Transactions

AMERICAN
FOUNDRYMEN'S ASSOCIATION

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Production of Bronze Pressure Castings

By D. Frank O'Connor,* So. Boston, Mass.

Abstract

The production of quality pressure castings of bronze requires: (1) good melting practice, (2) pouring practice that will produce uniform solidification of the metal, (3) proper maintenance of equipment in each department and (4) good supervision of control.

Manufacture of cores, molding, molding sand and gating are discussed in detail. Data on the physical properties are also included.

Introduction

1. When producing pressure castings there must be kept in mind the many types of application together with the physical requirement to withstand internal pressure at normal and elevated temperatures. The engineer must have these thoughts in mind when designing the casting. The alloy or metals to be used depends on the service required. Many liquids, steam, gas, air, etc. flow through these castings and it is very important that they be safe and sound.

2. High quality standards have been established by manufacturers and consumers of pressure castings which are a distinct aid to the industry. The reaction has been widespread; refining companies have raised their standards on the metal they furnish, and manufacturers of foundry supplies have improved quality and are cooperating more closely with the foundryman in the ultimate production of perfection in their castings.

3. Each foundry has its own economic problems; the foundry's size, location, and production determines the practices and methods to be set up to get the best possible results under existing conditions. In a production foundry where castings of similar

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nature are made day after day, definite control can and must be maintained in each department.

4. In the foundry with which the writer is connected, the problem does not concern a single alloy but includes many mixtures which must be produced to meet specifications of the metallurgists or engineers in charge of the many industries which use the foundries product. To establish control, the services of the metallurgist is enlisted and with the cooperation of the foundry foreman, standard practices are set up. It must be borne in mind that the ultimate result must be sound pressure-tight castings and that they must be produced with the equipment at hand.

5. There are many factors that enter into the production of good sound castings. In our opinion, experience is most valuable and from this experience we have established practices in coremaking, melting, molding, gating, pouring, sand and metal temperature control that insures a maximum yield of good castings. Atmospheric conditions are also considered in the foundry practice. Without proper co-ordination of these factors, we cannot hope to obtain maximum results.

CORES

6. Cores are made by hand and machine. Local sands are used in making core mixtures. Oil is used for binder and weighed with sand for making up the mixtures. The sand is mulled to the proper consistency and contains not more than 3 to 4 per cent moisture. Grain fineness of 160 is maintained to produce a smooth finish and good permeability, allowing gases to pass off freely.

7. Most of these cores are blown on machines. A uniform core requires proper venting and a little experience will produce sound cores, hard enough to resist metal penetration. Cores must be not rammed too hard but only hard enough to hold their shape. They must be vented properly so that the molten metal will lay against them without causing blows or cutting in. This is important in the production of sound pressure castings inasmuch as the core must give against metal pressure as also must the molding sand.

8. The cores are baked at 450°F. in an automatically controlled gas oven. The baking time depends on the size of the core which must be allowed to bake slowly to insure proper strength.

MELTING

9. The physical properties in an alloy are no better than the material used. The practice is to purchase metals in ingot form to rigid specifications. Metal charges are made up of 40 to 60 per cent ingots and the balance in gates, castings and boring.

10. Open flame type and crucible furnaces are used for melting. The crucible furnaces are used for small melts. In an open flame furnace where the flame is in direct contact with the metal a proper metal zone is important. Proper combustion to prevent the absorption of gases or impurities is most essential. The furnace should be pre-heated thoroughly before metal is charged after which the metal must be melted rapidly and not over-heated to get maximum physical properties. This practice is applicable to most of the bronze alloys used for pressure castings. A few minutes before tapping low melting metals are added and thoroughly mixed in the bath of metal. The temperature of the metal is recorded, and heated until 50 to 100°F. above the pouring temperature. Heats of 700 to 1000 lb. are melted in this type of furnace. To insure proper melting conditions throughout the melt the flame is kept slightly on the oxidizing side and careful maintenance of the melting zone and the burners which regulate the combustion is necessary.

11. Steel ladles of 150 lb. capacity, lined with fire sand and preheated to white heat, are used for pouring. A few oz. of 10 per cent Phosphor Copper is placed in the ladle just before pouring, and when filled with metal, charcoal is placed on top to prevent further oxidization. This remains on the metal until it is poured.

12. One of the advantages of the open flame type of furnace is its ability to oxidize and remove impurities which tend to cause porosity. However, metal losses can be relatively high, and careful supervision is required to hold these at a minimum.

POURING

13. Pouring temperatures are extremely important and are a guiding factor in our melting practice. Pyrometers are used in recording the melting and pouring temperatures. The pouring temperature of any casting depends on the design, gating, size and type of casting, and the alloy to be poured. The castings are submitted to a severe air test under water and the value of controlled

practice is shown by the fact that our loss due to porosity is less than one half of one per cent. It has been the author's experience that altering the gating to permit higher pouring temperatures reduces porosity. Metals poured at high temperatures produce a greater depth of sound chilled surface, so necessary for pressure tightness after machining.

14. To get maximum physical properties and pressure tightness with the majority of the bronze mixtures, the practice is to pour the metal for light and medium size castings between 2150 and 2250°F. with sufficient gate and head for a uniform rate of solidification. Heavier castings are poured at lower temperatures, but not under 2100°F.

15. To control pouring properly, the first step is to see that the ladle or crucible in which the metal is to be poured is preheated thoroughly. The size of the pouring ladle or crucible depends entirely upon the size of castings to be poured and the quantity of molds that can be poured within the pouring temperature range.

16. Each job has a definite pouring range. At the author's plant, a large variety of pressure castings are made, ranging in weight from 3 oz. to 400 lb. A ladle of 150 lb. capacity was found to be most economical and satisfactory to pour the greatest number of molds within the pouring range and still obtain maximum results. To aid in the pouring, a strainer core is set in the mold at the base of the sprue, which prevents the high temperature metal from cutting into the molding sand. The sprue is kept full while pouring and the metal enters the cavities under pressure rather than running in by gravity. In the writer's opinion the best physical properties and soundness are obtained pouring in this manner. The rate of solidification is more uniform, permits pouring at higher temperatures, and the metal does not cut into the sand.

17. The pouring temperature is taken at the molding floor and the metal is stirred well before pouring. The average drop in temperature from the first to the last mold is 40°F. on small and medium size castings. The metal is covered with charcoal throughout the pour preventing excess oxidization. Molds are poured horizontal.

MOLDING

18. In a production foundry, proper maintenance of equipment is absolutely necessary. There are many factors that enter

into the production of good molds such as type of pattern, maintenance of flask equipment, ramming, peening, squeezing of molds, size of flask and sand. In our foundry the largest production is from molding machines. Although less skill is required in machine molding, the human element still remains, and it is possible to easily produce defective work through lack of education in the fundamental principles of molding. Split type patterns are used and mounted on iron plates. Machines are of the plain squeeze and jar squeeze type. The size of flasks is 12x16x3½ in.

19. To maintain control of melting and pouring practice, molding, gating and sand conditions must be taken into consideration. Probably the most important are the combined factors of sand and ramming, peening and squeezing of molds.

Molding Sand

20. New sand is purchased to A.F.A. specification. Two grades are used No. 2E and No. 3E. A facing sand is made each day by adding one part 2E new sand to 25 parts of used sand and mulling for 5 min. Water is added during the mulling to a moisture content of 5 to 6 per cent. The permeability and strength are also checked and temperature of the sand recorded. The 3E sand is added to the heap periodically to maintain permeability. It has been found that sand control is necessary to produce castings with good surface finish and free from pit or gas holes under the surface. The practice is to have the moisture content as low as possible, permeability and strength high. The sand should be at room temperature or warmer, if possible, but not above 90°F. It has been our experience that pouring in warm sand produces a greater yield of good castings. This prevents the building up of great pressures within the mold and allows the gases to escape freely.

21. Physical properties of the sand used are:

Moisture	Permeability	Strength
4.5 to 5.5 per cent	18 to 20	5 to 6 lb. per sq. in.

22. Excess jar ramming, hand ramming or squeezing lowers permeability, preventing the metal from flowing properly against the sand. This causes blows, scabs and intercrystalline porosity. As each pattern presents its own problem in ramming and squeezing, the machines are equipped with pressure gauges and care is taken to see that jobs are assigned to the machine with proper flask equipment. The flask, especially the cope half, must be deep enough

to prevent a hard squeeze. Where jar ramming is used, the center of the mold is inclined to be the hardest and to equalize the mold hardness, the sand is often spread to the outer edge of the flask and built up to allow a greater pressure from the squeeze. Experience soon develops the proper mold hardness for a given job. A mold should not be rammed any harder than is necessary to resist metal pressure and assure perfect casting form.

Gating

23.   Gating is, of course, very important from the standpoint of producing sound castings and getting maximum yield from the tonnage poured. The location of the gate depends on the composition melted, and the design of the casting. At any time during the day, our schedule may call for the production of one or several alloys of red brass ranging anywhere from 76 to 88 per cent copper, 2 to 10 per cent tin, 1 to 14 per cent lead, and 0 to 15 per cent zinc. At one time, it was necessary to alter the gating for the particular composition melted. This was expensive and held up production. After careful study of pouring temperatures and sizes of gates, a size and type was arrived at that would suffice for all these alloys. The majority of the castings produced are fairly uniform in design and gate uniform in size will produce good results. The size of the gate depends on the size of the casting and the number of pieces that are poured in the mold.

24.   In determining gating, the first consideration is the position of the gate on the pattern, second, the number of patterns to be plated, and third, the pouring temperature. Although common practice is to provide generous gating, our studies indicate that pouring at higher temperature permits smaller gates. They must be sufficiently large, however, to prevent internal shrinkage and cracks. It is also common practice in a production foundry to get as many pieces as possible in a mold. Taking these factors into consideration the gating is mounted using round stock wherever possible, thus leaving no sharp edges. It is difficult to say what size runners or gates would suffice for all jobs. Many foundrymen differ as to methods of gating. In a production shop, with a little experimenting, a method of gating can be established that will be economical and produce maximum yield in castings. With the method of pouring and gating used by the author's company it is possible to gate castings of uneven sections on the lighter end, thus feeding

Table 1

PHYSICAL PROPERTIES OF BRONZE PRESSURE CASTINGS

Type	Yield Point lb. per sq. in.	Tensile Strength lb. per sq. in.	Elongation Per cent
85-5-5-5 ....15,000 to 18,000		35,000 to 38,000	20 to 40
Comp. "M"			
46-B-8F ....18,000 to 19,500		40,000 to 43,000	30 to 45

the heavier section first. This automatically reduces the size of the gate at the pattern junction and requires only a runner sufficiently large to feed the casting at that end. It is sometimes more economical to gate at the heavier section of the pattern where the quantity of pieces in a mold can be increased. Contrary to some molding practices, the gating on either the heavy or light section has no effect on our pouring practice.

25. Leakage under pressure is usually due to porosity. The leak may be caused by poor pouring, pouring at low temperature, or pouring beyond the pouring range, or from hard ramming which did not permit the metal to solidify properly. Other causes may be over-heated metal, excess moisture and low permeability of the sand, or poor gating. As porosity seems to be the major defect in the production of pressure castings, proper control of these factors should ultimately reduce the losses. With a control set up, it is possible to trace the losses to definite causes. Thereby enabling necessary changes to be made and practically eliminate the loss.

26. It is a simple matter to control pouring, pouring temperature, pouring range, and the moisture of the molding sand. In the author's opinion, these are the causes of a great percentage of porous castings. The practices are not difficult to set up; the important thing is to maintain them. With these practices, losses on pressure casting due to porosity is less than $\frac{1}{2}$ of 1 per cent.

27. The physical properties of the castings are as shown in Table 1.

CONCLUSION

28. The production of quality pressure castings of bronze requires:

(1) Good melting practice.

(2) Pouring practice that will produce uniform solidification of metal.

(3)   Proper maintenance of equipment in each depart-
      ment.

(4)   Good supervision of control.

29.   A production foundry presents problems unlike those of
a jobbing foundry. In either case, however, a thorough knowledge
of the fundamentals is essential.

DISCUSSION

Presiding: WM. M. BALL, JR., Edna Brass Mfg. Co., Cincinnati, O.

T. E. KIHLGREN[1] *(Written discussion):* This paper gives practical
suggestions on the establishing of suitable foundry control of the many
factors entering into the production of sound pressure tight castings.
The low percentage of rejects due to porosity, and the excellent physical
properties reported by the author on two of the mixtures cast by the
foundry concerned, demonstrate well the value of such control.

The author refers to the addition of charcoal to the ladle after the
deoxidation treatment. I think it would be well to insert "pre-heated"
before "charcoal" as the addition of charcoal containing moisture will
introduce hydrogen, resulting in unsoundness.

It is also interesting to note that the author recommends a some-
what oxidizing melting atmosphere, and I think this reflects a view
which is much more commonly held by the non-ferrous foundryman to-
day than it was years ago. It is now fairly well recognized that the
presence of hydrogen in the molten metal is highly undesirable in cop-
per base alloys. This invariably leads to castings containing capillary
voids (or "incipient shrinkage") resulting in "leakers". The use of a
moderately oxidizing flame is helpful in eliminating, or at least reduc-
ing, unsoundness from this source. In some instances, where conditions
are such as to provide a quite reducing atmosphere during melting, the
deliberate oxidation of the melt with 0.1 to 0.2 per cent of copper oxide
may be found helpful. Such a procedure probably will not be useful
where ingot containing readily oxidizable constituents such as lead,
zinc, etc. is used, but where castings are produced from virgin metals,
deliberate oxidation prior to the addition of remelt and of zinc, tin and
lead merits some consideration, where the circumstances permit its use.

It is to be regretted that the discussion of gating was not amplified
and illustrated in view of its extreme importance. A few photographs
of castings with gates and risers attached showing gating and feeding
methods found most satisfactory for several different types and sizes of
castings, or, in lieu of photographs, sketches, schematically depicting
the gating methods used, would have been most helpful. It is hoped that

[1] International Nickel Co., Bayonne, N. J.

the author will find it possible, before final printing of the paper, to amplify and illustrate this portion of the paper dealing with possibly the most important single factor, granting that all the variables need to be understood and controlled to get a consistently high yield of good castings.

G. M. THRASHER[2] *(Written discussion):* The writer has enjoyed this paper and noted that most of the author's experience parallels his own. A difference, however, is shown when the author stated that the temperature drop in his 150 lb. ladle amounted to only 40°F. while pouring.

Several years ago, checking on a 180 lb. ladle of similar construction and lining, I found the drop in temperature to be about 35°F. per min., checked at intervals of 1 min. while pouring castings. As the time required varied between 4 and 6 min., depending on the type and size of the castings, the total drop varied from 150° to 200°F.

These tests led to the use of a larger ladle bowl in which a light weight straight side crucible was used and insulated from the bowl with diatomaceous earth.

Tests on the insulated pouring crucible showed only 20°F. drop per min.

MR. THRASHER: Mr. O'Connor showed us a number of gates on valve castings. Just what is the shape of the gate as it enters the mold proper between the runner and the casting?

MR. O'CONNOR: The runner is half round. It is supposed to be round. Round gates are used wherever possible.

In answer to Mr. Kihlgren's written discussion, so far as charcoal and its use is concerned, it is kept in a dry place, but not dried out. There is about 3 per cent moisture in the charcoal when applied and evidently it does not absorb any hydrogen gas.

I have here a sample casting made in a cement mold. It was made purposely to eliminate, all the moisture that we could in the sand without baking. If you look at it you will find out there is very little trace of any absorption of gases.

MEMBER: Did you notice any absorption of hydrogen from wet coke when melting in a coke fired furnace?

MR. O'CONNOR: My experience on pit furnaces is very limited. But in hardware work where I had some experience, I could not trace moisture as causing any so-called gas holes under the surface of the castings when polished, for we tried to keep the coke fairly dry.

CHAIRMAN BALL: Do you have any trouble with incipient shrinkage in your gate? In one of the castings you show a small gate and

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[2] R. Lavin & Sons, Inc., Chicago, Ill.

that small gate will not feed the big casting. The large casting would
have its feeding cut off by the strainer core.

Mr. O'Connor: Others seem to have the same opinion that in-
cipient shrinkage would show there but it does not. These molds are
poured horizontal.

Member: At what temperature did you pour that gate valve you
showed?

Mr. O'Connor: At 2200°F.

Member: In using charcoal for covering our metals, from our
experience, we have found that crushed glass on top of the metal pre-
vents a lot of oxidation and absorbs gas better than does charcoal.

Mr. O'Connor: We found that the glass adheres to the sand and
gives you trouble in cleaning out the pot, whereas charcoal gives no
trouble at all.

Member: Does the size of the sprue have any relationship to the
size and number of fingers or gates going into the casting? I notice
nearly all your sprues seem to be an inch in diameter.

Mr. O'Connor: They are 1¼-in. in diameter. The sprue has no
definite relation to the size of the branch runner or gate runner. We
established that size because it is more uniform for all metals. We can
run an alloy of 16 per cent zinc and still use the same sprue. Where
we try to control the rate of pouring, we have an 18-hole strainer core
and a 9-hole strainer core. The holes are $\frac{1}{16}$-in. in diameter. The volume
of metal in the sprue is a little greater than the volume in the runners.
We want to make sure of that because we want a choking effect to
insure good clean metal. We want to have the metal run along smoothly
and not increase in velocity and cut in the sand.

Member: The author stated that in pouring this casting he used
a certain proportion of ingots, sprues and gates and some borings.
Suppose instead of having borings you have a bunch of trolley wires,
say, in the form of briquettes which are highly oxidized, what effect
would an addition of that kind have on the porosity of the casting?

Mr. O'Connor: I am afraid of copper in the form of briquettes.
There is a possibility of it picking up gases. There seems to be a
tendency for copper, melted either in the form of briquettes or in the
pure form to absorb gases.

High Conductivity Copper Castings

By A. B. Kinzel*, New York, N. Y.

Abstract

The industrial available alloys which have high strength combined with high electrical and thermal conductivity are reviewed. When more than 80 per cent conductivity is required these precipitation type alloys are based on chromium, usually present as a silicide or beryllide. Nickel or cobalt similarly present result in 45 and 60 per cent conductivity respectively. Recently patented alloys with high conductivity are discussed together with the effects of silver, cadmium, tin and zinc, and the melting practice is considered with special reference to the roles of deoxidizers, graphite, iron and phosphorus. In conclusion, uses of the alloys are cited and a plea is made for cooperation between scientist and foundryman.

1. The term "high conductivity copper castings" has been variously applied to cast copper and copper alloys which have a conductivity in excess of 30 per cent. With the developments of recent years, the term more usually is applied to materials having a conductivity in excess of 45 per cent, and frequently a minimum of 80 per cent or more is specified. With the exception of unalloyed copper, all of the copper-base analyses that meet this specification contain chromium as an important constituent. The problem of producing high conductivity castings is not new, and unalloyed copper has been cast for this purpose for a great many years. Such copper presents many casting difficulties and many special deoxidation problems, so that while 80 per cent conductivity is frequent, values in excess of 85 per cent are obtained only rarely. Moreover, this material has all the characteristics of soft copper, such as low hardness and low yield strength, which render it unfit for many engineering applications.

THE PROBLEM

2. The major problem that faces the foundryman is to produce an alloy having consistently better than 85 per cent electrical conductivity, together with relatively high strength. The first satisfactory solution of the problem was due to Corson, who applied the principles of precipitation hardening to copper metallurgy. Corson reasoned, and subsequently proved experimentally, that copper—like aluminum—could be strengthened by means of precipitated particles, and that, by choosing the proper alloy, the precipitation treatment could be carried out so as to leave only small amounts of alloying ingredients in solid solution, thus combining strength and conductivity. This reasoning applies not only to the alloys as originally developed by Corson, but as well to all of the high conductivity coppers developed since that time.

3. Consideration of the solubilities of most of the possible alloying elements shows that only chromium or chromium compounds may be so precipitated that the amount of element remaining in solid solution is insufficient to reduce the conductivity below 85 per cent. Chromium, in itself, fails to give the optimum strength which can be obtained in combination with this conductivity, and the alloys of chromium and other elements, particularly silicon or beryllium, have been developed to meet this dual requirement.

Silicon Used with Chromium

4. Silicon was the first alloying element used in connection with chromium for achieving the desired precipitation effect. The alloys containing from 0.06 to 0.12 per cent silicon and chromium in excess of 0.50 per cent have been developed industrially. On precipitation treatment, these alloys yield several chromium silicides, and, in addition, chromium itself is precipitated, if present in excess with respect to the silicon. Thus, there is no fixed ratio of chromium to silicon necessary for achieving practical removal of both of these elements from solid solution. Moreover, the chromium silicides are sufficiently stable so that only very small quantities of silicon remain in solution to decrease the conductivity. In order to keep this small amount at a minimum, it is generally advisable to use ten times as much chromium as silicon. It should be stressed that excess silicon is definitely harmful in these alloys. One very popular composition comprises 0.08 per cent silicon and 0.80 per cent chromium.

Heat Treatment

5. Heat treatment is, of course, essential to obtain optimum properties. This involves a solution treatment of two hours' heating at 925°C. (1742°F.) water quenching to retain the chromium and silicon in solution, and subsequent reheating at 500°C. (932°F.) for one hour or more with furnace cooling, to produce precipitation. It is noteworthy that these alloys respond to heat treatment even in comparatively large masses, that is, "mass effect" is almost absent.

6. It should be particularly noted that while satisfactory dispersion of the precipitate is required to produce optimum yield strength and ultimate strength, it is not at all necessary in order to produce optimum conductivity. The latter is purely a function of the reheating or tempering treatment, and in many cases it may be desirable to use the low temperature treatment alone, thus producing material having some 85 per cent conductivity and all the other properties of usual soft wrought copper. Obviously such a treatment eliminates the quench, and this, too, has no effect on the conductivity.

Properties

7. The full heat treatment results in a conductivity of 85 per cent or more, 35,000 lb. per sq. in. yield strength, 52,000 lb. per sq. in. ultimate strength and some 13 per cent elongation in 2 in. In this state, the alloy has a Brinell hardness of approximately 100. Hensel reports 25,000 lb. per sq. in. fatigue strength for these alloys.

8. Perhaps more important than the figures just quoted is the nature of the stress-strain curve. This consists of a line that is practically straight up to some 25,000 lb. per sq. in., so that up to this limit, the material, as used for engineering purposes, may be treated in design as thoroughly elastic.

9. Intercrystalline brittleness has been observed in this material when improperly prepared. It is probably associated with oxide films and is not present in material properly cast and heat treated.

Properties at Elevated Temperatures

10. Remarkably, this straight line characteristic, together with the properties just quoted, is retained at moderately elevated temperatures. While there is some loss in creep strength in these alloys as in all copper base alloys, it is noteworthy that tests for

one month at 15,000 lb. per sq. in. at 400°C. (752°F.) have shown
no appreciable creep in the alloy, and the mechanical properties
deteriorate only very slowly at temperatures below 500°C.
(932°F.). Hensel reports better than 45 ft.-lbs. impact retained
up to 400°C.

NICKEL AND COBALT ALLOYS

11. Other silicide precipitation alloys of copper have been
developed, particularly those using nickel and cobalt to form
silicides. However, these silicides are less stable than the chrome
silicides, more silicon is left in the solution, and the resulting con-
ductivities are of the order of magnitude of 45 and 60 per cent
respectively. These may be of interest when combined with the
increased yield strength and ultimate strength obtained in such
alloys, but cannot be considered as high conductivity castings in
the most modern use of the term. In these alloys, it is important
that a fixed ratio of nickel or cobalt to silicon be maintained, as
any excess remains in solution. About 4.2 nickel or cobalt to silicon
is the optimum ratio to produce maximum Ni_2Si or Co_2Si. Any
insufficiency of nickel or cobalt allows more silicon to remain in
solution, and too much results in nickel or cobalt in solution. In
either event, the conductivity is seriously impaired.

Properties

12. Typical of the alloys in question is copper containing
2.5 per cent nickel and 0.60 per cent silicon, which has a yield
strength of 65,000 lb. per sq. in., an ultimate strength of 75,000
lb. per sq. in., a Brinell hardness of 140, and a conductivity of
45 per cent after quenching from 850°C. (1562°F.) and tempering
at 425°C. (797°F.). Cobalt alloys containing 2.4 per cent cobalt
and 0.6 per cent silicon are intermediate in properties to the nickel
and chromium combinations, but have not been industrially
produced. Substitution of phosphorus for silicon in the cobalt
alloys, without appreciable loss of conductivity, and a similar alloy
containing manganese and phosphorus, with somewhat lower con-
ductivity, has been described by Hensel and Larsen, but there is
no indication that these have been used as castings.

BERYLLIUM ALLOYS

13. Subsequent to development of the silicide alloy, a
beryllide type, analogous in all respects to the silicide type, was
invented, the nickel-beryllide by Corson and later the chromium

beryllide by Harrington. Straight beryllium-copper subjected to a precipitation treatment has long been known. Even when following the Corson heat treating principles, the amount of beryllium left in solid solution is so great that a conductivity in excess of 30 per cent could not be expected. The introduction of nickel or cobalt, together with beryllium, results in alloys having characteristics very similar to those of nickel or cobalt-silicon alloys—again with a limitation of some 50 and 65 per cent electrical conductivity. Chromium, together with beryllium, gives results entirely analogous to those obtained with chromium-silicon-copper. This is entirely logical, as the properties are purely a function of the copper matrix and the precipitated particles, and the substitution of beryllium for silicon does not affect the purity of the matrix and does not change the physical disposition of the precipitated particles. Thus, like the chromium-silicon alloys, chromium-beryllium alloys develop 85 per cent minimum conductivity after heat treatment, and the other physical properties are so similar to those of the chromium-silicon-copper that any difference would be found only within the normal limits of variation. Beryllium alloys do have an advantage over the silicon alloys, in that they are definitely more immune to improper heat treatment. The rate of precipitation and the rate of coalescence of the beryllides are apparently less than that of the silicides, so that in certain critical temperature ranges, such as in the vicinity of 550°C. (1022°F.), beryllium alloys will retain their hardness for appreciably longer periods than will the silicon alloys.

Modification of Alloys

Silver and Cadmium Additions

14. The alloys in question have been modified with other addition elements, notably silver, cadmium and tin. While the simple addition of silver to the chromium-silver or chromium-beryllium alloys apparently has little effect, Hensel and Larsen claim that the substitution of silver for silicon or beryllium resulted in an alloy of high hardness and further improved conductivity. For example, they cite an alloy containing 0.39 per cent chromium and 0.044 per cent silver, with a hardness of 136 Brinell and 90 per cent conductivity, and another alloy containing 0.31 per cent chromium and 0.1 per cent silver, with a conductivity of 96 per cent and a hardness of 128 Brinell. Hensel and Larsen have likewise added cadmium to a copper-chromium base, and cite 1 per

cent chromium and 2 per cent cadmium as resulting in 90 per cent conductivity and 116 Brinell. Further, Hensel has added both cadmium and silver to a copper-chromium base. He claims added castability and fluidity, improved high temperature properties, together with retention of appreciable electrical conductivity, and hardness in the order of magnitude indicated above. However, there is very little in the literature on this subject, and apparently no data are available to confirm the above which is quoted from their patents.

Tin and Zinc Additions

15. Tin has been added to the copper-chromium-silicon base alloy, but even in small amounts, this has an appreciable adverse effect on the conductivity. It is said to improve castability and moderately increase strength and corrosion resistance. The tin content is necessarily limited to a few tenths per cent, and it is understood that this composition is used in the production of one popular electrode. Zinc likewise may be added to the alloys in question. However, it does decrease the amount of silicide or beryllide that can be taken into solution, thus lowering the maximum strength which may be obtained, and except when present in very small percentages, it seriously affects the conductivity. Very small amounts in solution have minor effect on the conductivity, as zinc differs from such elements as phosphorus and silicon in this respect.

Melting Procedure

16. The alloys in question may be prepared without particular difficulty if it is borne in mind that the chromium, silicon and beryllium are readily oxidized. The usual procedure for the chromium-silicon alloy involves preparing a bath of copper under a cover. This cover may be charcoal, salts such as a mixture of sodium and calcium flouride, or glass. After the copper is melted, it may be deoxidized with any one of a number of special deoxidizers; copper-magnesium, calcium, calcium-silicon, calcium-boron, manganese-boron and sodium have all been mentioned in this respect, but zinc is probably the most effective deoxidizer. An addition of 0.2 per cent zinc has been used in this stage of the heat with success. Actually, there is little need for deoxidation of the metal in this way, because the subsequent silicon addition is in itself a very effective deoxidizer. The only merit in using another

deoxidizer lies in the fact that it enables somewhat closer control
of the final silicon content in the alloy.

17.   In the case of the nickel or cobalt alloys, this element
may be added with the initial copper or after initial deoxidation.
Silicon is then added to the bath, either as silicon metal or prefer-
ably in the form of a master alloy containing 30 per cent silicon.
It is usual to obtain complete recovery of silicon from this addition.
Shortly after the silicon addition, the chromium is added, generally
as the master alloy containing 10 per cent chromium, although
briquetted copper-chromium is also used.   The copper-chromium
master alloy is available in the form of shot and as pig. The most
consistent results are obtained with the pig and it is generally
recommended; a recovery of 90 per cent of the chromium is usual.
Lower recoveries have been reported, but in these cases either no
cover was used on the bath or little attention was paid to the state
of deoxidation at the time of the addition. Five minutes is generally
sufficient to dissolve the chromium, and the melt should be cast
as soon thereafter as the desired casting temperature is reached.
In order to get either silicon or chromium into uniform solution
throughout the metal it is usual to stir, but only a single stirring
is necessary and prolonged stirring should be avoided. Overheating
should likewise be avoided.

18.   Graphite stirring rods are recommended for this opera-
tion to avoid iron contamination. Graphite skimmers are likewise
indicated. Although there has been some discussion as to the pos-
sibility of the formation of chromium carbides which would result
from use of a graphite utensil or charcoal cover, all of the evidence
tends to prove that such carbides do not form at the temperature
and conditions in question and that there is no reason from this
standpoint against the use of either a charcoal cover or a graphite
utensil.

Casting Practice

19.   Casting temperatures vary with the mold to be filled, but
are generally on the hot side with respect to other types of copper
castings. Normal gate and sprue practice may be used in molding,
but care should be taken to avoid pockets in the mold, as there will
be a tendency toward shrinkage in specific locations. In this con-
nection, it is interesting that general porosity has never been
observed in these castings, as the metal treated with chromium and

silicon is free from gases which are evolved during freezing. This has been further shown by Corson in density measurements carried out by the same procedure as reported in his paper before the Institute of Metals, last February. These ranged from 8.84 to 8.94 and compare favorably with the very best deoxidized copper. However, an oxide skin may form in pouring, and with improper mold design, this may result in folds and porous shrinkage zones. Darby reports freedom from this condition when small amounts of phosphorus are added, the phosphorus being present in the final casting as a eutectic having practically no effect on the conductivity.

Iron Contamination

20.   Iron contamination, in the preparation of the alloys in question, seems almost inevitable, but the amounts are small. The iron, even in small amounts, has an adverse effect on the electrical conductivity. It has been found that such iron can be taken out of solution by means of phosphorus, which makes possible a more complex alloy in which chromium-silicide, chromium phosphide and iron phosphide are present. However, little has been published on the subject as yet, and the question of the exact nature of the chromium iron-phosphorus content remains. It may be analogous to the cobalt and manganese phosphides previously mentioned.

Casting Beryllium Alloys

21.   In the casting of beryllium alloys the same basic procedure is followed as in the casting of the silicon alloys. More attention is paid to the initial deoxidation in order to increase beryllium recovery, which, in good practice, generally exceeds 90 per cent. Beryllium is added as the master alloy containing some 4 per cent beryllium. One major difference exists between the beryllium and the silicon type alloys, in that it has not been deemed practicable to cast pigs or blocks of the silicon alloys and simply remelt, whereas this practice has been followed in the case of plain copper-beryllium alloys. As yet, it probably has not been practiced with the alloys containing only 0.1 per cent beryllium.

FIELDS OF USE

22.   The alloys in question are used primarily because of their high conductivity combined with physical characteristics which adopt them for engineering applications both at room temperature and at moderately elevated temperatures. The term "con-

ductivity'' as used above, refers not only to electrical conductivity but also to thermal conductivity, and, as would be expected, high thermal conductivity accompanies high electrical conductivity in these materials. The alloys are used in connection with electrical machinery where the combination of high conductivity and physical properties is required. Electrodes for resistance welding present another important use of the alloys. These are found not only in the form of special cast shapes, but also as large cylindrical and conical rollers and similar pressure contacting devices. Both of the above types of application depend largely on electrical conductivity, but, in the case of electrodes, the thermal conductivity may play a role.

23. There are still other applications where thermal conductivity in conjunction with high strength is the sole factor and electrical conductivity plays no role whatever. These are best illustrated by the internal combustion motor head; here the high heat conductivity results in improved motor efficiency, and the strength retained at moderate temperatures allows the material to meet the tensile requirements. Other applications in motor parts are to be expected as the art develops.

CONCLUSION

24. While the alloys in their present industrial applications represent a nice combination of the foundryman's art and the science of the physical metallurgist, it is not at all necessary that the foundryman be a scientist in order to produce the material. However, it is well that he have some understanding of the principles on which the properties of the alloys are based, so that he may pay due attention to the specifications covering both analysis and heat treatment. Although the foundryman need not be a scientist to achieve the desired results, it is quite necessary for the scientist to be a foundryman to successfully produce these materials, as they do not differ from other copper-base castings in requiring the best of the founder's art. In the last analysis, all of the prescriptions and specifications are intended to apply to sound castings, and all of the predictions for high conductivity and high strength are based on the assumption that the foundryman will produce such castings.

DISCUSSION

Presiding: Harold J. Roast, Canadian Bronze Co., Ltd., Montreal.

In the absence of the author, the paper was presented in abstract form by C. O. Burgess, metallurgist, Union Carbide and Carbon Research Laboratories, New York, N. Y.

Wm. J. Laird:[1] The statement has been made in the paper, that in order to achieve the optimum physical properties there is a necessity of having a ternary alloy, that the copper base material should be impregnated with a chromium silicon. Now so far as I can tell, from the experience that we have had with this type of alloy, it is not necessary that you have more than a binary alloy to achieve characteristics which are on the order of 35,000 lb. per sq. in. yield, 50,000 lb. per sq. in. ultimate strength and, let us say, conservatively, 120 Brinell hardness, with conductivities on the order of 80 to 85.

While I will agree with the author that silicon is a potent scavenger for cuprous oxide, assuming that you are making your alloy, compounding it from virgin materials and melt down your copper, and you add to the molten bath chromium either as such or in whatever form you may see fit, depending upon your intent to form a silicide or beryllide, it is well I think, for the casting, if the metal be previously deoxidized without the use of silicon. As I said, I agree silicon is a thorough scavenger of cuprous oxides. But the end product of cuprous oxide and silicon reaction is a gray powder precipitate which, in spite of its inferior density, does not thoroughly gravitate from the melt and is generally found on the top side of your casting against the cope. This is not the case in those instances where a relatively insoluble, as we call them, deoxidizer is used. There are a number of these. Lithium is being advanced. Calcium boride is well known. Calcium silicon is less scruffy than silicon. These various deoxidizers tend to give a liquid slag which does not leave residuals entangled in the bath. I mean by that, of course, the result of the deoxidizing reaction.

Insofar as graphite stirring rods in the recommended practice for melting procedure is concerned, the use of graphite stirring rods, is probably the right thing. I myself am of the opinion that iron, particularly after heat treatment, is not harmful to these alloys. I am talking of both the binary and ternary alloys.

As to the use of tin and zinc additions as auxiliaries or adjuncts for various deoxidizing purposes, I do not feel they accomplish any purpose. I will agree they are thorough scavengers like silicon, but why use them when they have no hardening effect and tend to depress conductivity inasmuch as they are soluble?

I would say over all the paper is excellent. The properties given are rather conservative. We, at Westinghouse have made what we call

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[1] Metallurgist, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

chromium-copper castings, which are in reality chromium-silver-copper castings. In one particular casting we poured 17,400 lb. into the casting with a casting yield in the order of 9,000 lb. This casting had a Brinell hardness average of 112. It had a chromium content of approximately 0.57 per cent. That was the one instance in which we attempted to melt chromium-copper in an open flame furnace. The losses were terrific.

I note the author states the recovery of chromium is around 0.9 per cent. It is my opinion that such recovery is high with the best practice, at least that we happen to know about. Our recovery is probably near 0.7 per cent.

I would be very much interested in Mr. Corson's reaction to the binary as against the ternary alloy insofar as approaching the optimum properties is concerned, as the author has seen fit to call them.

M. G. CORSON:[2] My position is somewhat difficult. As at present I have had extremely little contact with the use of any of the many alloys I have developed. So, I shall treat the subject from a purely historical viewpoint. Working for the Electro Metallurgical Company I was entrusted with the investigation of copper alloys, especially those with chromium. My first melts were made in a pure graphite crucible, lined with loosely sintered magnesia, and heated in a 35 KVA high frequency furnace and I had to use copper-chromium shot (10 per cent) to introduce my chromium.

Today we know well enough that at a temperature of not over 1260°C., as met in the ordinary pit fire, chromium is quite neutral toward graphitic carbon, perhaps even toward charcoal. At that time the idea prevailed that chromium combines with carbon avidly, and for this reason the use of a pot and a gas fired furnace were out of question.

So, my first alloys were full of oxides and the amount of dissolved chromium was beyond control. However, I could easily manage to get about 1 to 2 per cent of chromium in the alloy by using a reasonable excess—about 50 to 100 per cent extra.

The heat treatment of these alloys—and I hit the proper homogenizing temperature (900°-950°C.) and the proper aging temperature (450°-540°C.) almost with the first try—did not bring about uniform results. A conductivity of 70 per cent with a hardness of 100 Brinell, or a hardness of 80 Brinell with a conductivity of 80 per cent, would be only the average figures of the discrepancies I received.

This lag in the maximum improvement figures intrigued me very much, and I decided that I might precipitate much easier and more uniformly some compound of chromium. Which one? It was obvious that the second element of that compound must be soluble in solid copper, and must have a stronger affinity for chromium than for copper.

[2] Consultant, New York City, N. Y.

The first condition could be satisfied from data known. The second—from general chemical knowledge and a chemical "feel." So I decided upon silicon, phosphorus, beryllium. I concentrated upon the first, although I established also, that phosphorus is not potent in the direction wanted, and that beryllium does well as a substitute for silicon in the case of nickel and cobalt, so, by analogy it ought to do the same for chromium.

I established soon—while using as much as 2 per cent chromium (remaining in the alloy) and various amounts of silicon—that three different compounds may form, to wit:

(a) With very small amounts of silicon a sharply crystalline (chromium is globular) compound appears. In cross sections the square and triangle forms predominate.

(b) With larger amounts another crystalline substance forms. It appears in the shape of elongated romboids.

(c) With still larger amounts of silicon (from 0.35 to 0.55 per cent of the amount of chromium) a third compound takes place. It appear in the shape of "needles."

At that time I did not know what compounds they represented. Today I am certain that they were: Cr_3Si, Cr_2Si, and $CrSi$.

Cutting down on the chromium and silicon until there was about 0.60 per cent chromium and 0.10 per cent silicon, I managed to get the whole in solid solution on homogenizing. Drawing at 500°C. gave me immediately concordant results, with the pick in hardness and strength attained at the same time.

That is why the silicon addition was adopted. Beryllium also could be used and at the present price of $23.00 per lb., the introduction of the 0.07 per cent beryllium needed means only 1.5 cent extra cost per lb. At that time, with beryllium at $200.00, it was hopeless to try and use this element.

Later on I took the "daring" step of making my alloys in a plain crucible, using a liquid cover of two parts soldium fluoride, to one part of calcium fluoride. The pure fluorides melt considerably above 1100°C., while the mixture mentioned is fluid at 980°C. Proceeding in that manner I was able to recover my chromium to 90 and even 95 per cent. Once pushed down through the liquid flux it is protected, and must only be allowed enough time, with but little stirring, to dissolve completely. I think that low recoveries are most frequently due to errors in the determination of chromium by the laboratory.

Concerning deoxidation. I do not think it to be logical to fight much, as is the custom, against the oxygen in the alloys. Copper frequently carries as much as 0.04 per cent oxygen without any direct ill effects, and even 0.2 per cent oxygen in the otherwise pure metal does not lower its mechanical characteristics.

The most potent deoxidizer in the trade is a master alloy containing calcium and silicon. Used in quantities that can barely eliminate 0.01 per cent oxygen it yields excellent metal, although as much as 0.05 per cent oxygen must remain. Taken in quantities, sufficient to completely deoxidize the metal, it ruins it completely.

The reason is that the deoxidizers do not deoxidize. They change the solubility of the absorbed gases and cause the metal to lose the latter rapidly, so that on the arrival at the mold the metal is practically gas-free.

I advocate, however, the use of a deoxidizer, simply for the purpose of better controlling the silicon and chromium content. And no other metal does it better than zinc. Put one per cent of standard brass in the metal before adding silicon and chromium. Its zinc (0.33 per cent) will easily eliminate 0.08 per cent oxygen. Suppose you have no oxygen at all in the melt? Then the remaining zinc will go into solid solution and cut the metal's conductivity by 3 per cent—maybe! Probably much less.

There is no point whatsoever in using tin. Tin oxide might easily remain in the alloy in the shape of films. Possibly they would be rather harmless, but they can not improve the alloy. And what tin remains lowers the conductivity to a great extent.

I do not wish to condemn offhand all other deoxidizers although, I would not advise their use. My experience with lithium was not satisfactory. I was getting low strengths and the fractures were always discolored, a brick red tinge coming up here and there.

Of the two other types of copper base alloys discovered by myself I can say the following:

Cobalt silicide, as well as cobalt beryllide, can be precipitated rather completely as long as the cobalt : silicon ratio is kept under close control. If, however, one of the two predominates to the extent of but 0.1 per cent, the resulting conductivity will be 10 per cent too low. So, while a conductivity of 62 per cent was obtained by the author on occasions, normally it would not go beyond 52 per cent, probably less.

Nickel silicide does not precipitate so completely and about 0.12 per cent silicon, and 0.55 per cent nickel, remain in solid solution after heat aging, which results in a conductivity of not over 50 per cent.

But the ratio nickel : silicon does not have to be so painstakingly controled. It may deviate considerably from the desirable one of 3.20 : 0.75 per cent, but the deviation must not give silicon a predominance. With 0.80 — 3.20 per cent one will have 0.05 per cent silicon in excess. With 0.70 per cent there will be an excess of 0.21 per cent nickel. But the conductivity will be much more reduced by the 0.05 per cent silicon, than by 0.21 per cent nickel.

One point must be remembered regarding copper-nickel-silicon and copper-cobalt-silicon (also copper-nickel-beryllium and copper-cobalt-beryllium) alloys when used for castings. The grain of the casting is likely to be very big and a large amount of the silicide will be found at the grain boundaries. For this reason an alloy with over 3 per cent nickel, will possess but little or no ductility as cast. Will the silicide completely go into solid solution on homogenizing? One cannot treat a casting for a long time at 800 or 850°C. without ruining its surface and a short treatment might be quite insufficient. And should any amount of the silicide remain at the grain boundaries, the maximum hardness could not be reached, while the ductility will remain low. So, a preliminary study of each case shall be made before attempting to turn out commercially heat hardened "good conductivity" castings in copper-nickel-silicon or copper-cobalt-silicon.

MR. LAIRD: I cannot help but add in connection with this paper that here the non-ferrous foundryman has an alloy which has very admirable properties. And of course, it is to his interest to utilize it to the best advantage. Now entirely aside from the paper, one of the major things that works against the expansion of the use of the alloy is the cost. Unfortunately, perhaps, many of the active alloys are proprietary and, of course, there is a tariff attached to them which works against them. And then, in addition to that, they differ from the normal alloy in that they are heat treatable, which also adds an additional cost. Further than that, the introduction of the hardening constituents is generally in the form which requires some preliminary handling, commonly being briquetted and injected into the bath in that fashion.

On the face of it, with the physical characteristics which these alloys have, there is no reason why a copper casting should exist as such, with alloys at a design engineer's disposal having the properties that these alloys have. Design engineers of course think of an iron casting in terms of five or six cents a lb. and copper castings on the order of 25 or 26 cents a lb.; and when we come to the hardenable coppers which have been heat treated, we talk in terms of $1.00 a lb. —with the net result these alloys are being used only in those places where nothing else can be used reasonably. So it behooves us who have for once in the copper field an alloy which approaches in properties that of mild steel, to bring the cost of the part into line so that it may be competitive with the regular run-of-mine non-ferrous alloys that an engineer has at his command.

A. B. KINZEL (Author's Written Closure): The discussion offered by Messrs. Laird and Corson is appreciated, as it adds much to the value of the paper.

The question of binary alloys of the precipitation-hardened type, discussed in this paper, arises only in the case of chromium, as neither nickel or cobalt can be used alone in copper for precipitation-hardening

purposes, and since the copper-beryllium binary has already been treated. It has been our general experience that the degree of precipitation, uniformity of precipitation and ease of control of precipitation are more advantageous with the silicide of chromium than with the chromium itself.

As to deoxidizers, I would reiterate one of the points made by Corson, namely, that the major reason for deoxidizers, in alloys, which already contain silicon or other elements which readily form oxides, lies chiefly in the ability to control silicon content, so that any other deoxidizer, which is only slightly soluble, can be satisfactory.

The use of graphite stirring rods rather than iron stirring rods is mentioned in the paper because trouble has been experienced with lowered conductivity due to iron pick-up, and this iron pick-up has in at least one instance been traced to the iron stirring rod.

The matter of chromium recovery is one which cannot be treated categorically. In large open furnaces, with inadequate protection of the metal and possibly a comparatively high state of oxidation at the time of the chromium addition, lower recoveries are not surprising, but with the conditions as they prevail in many foundries today, a chromium addition to a low-oxygen copper bath does result in recoveries approximately 90 per cent.

Mr. Corson's historical review is particularly appreciated. His early work established the base for the entire development of high strength, high conductivity copper-base alloys, and his fundamental knowledge of the subject leads to clear thinking.

While it is common to add the alloying elements mentioned in this paper in the form of briquets, this method is not unique, as master alloys both in the form of pig and shot are likewise used. Mr. Laird's comment as to the cost of these materials is pertinent. However, it is probable that the basic reasons for what Mr. Laird terms "the high cost," are to be found in the special attention and special handling required from start to finish, rather than in the cost of the alloying elements, cost of the heat treatment or the tangible items of this type.

Those who entered into the discussion of this paper, as well as Mr. Burgess who so ably presented it, are accorded the author's fullest appreciation and thanks.

Report of the Committee on Radiography—1939

To the Steel Division, American Foundrymen's Association:

During the past year (May 1938-May 1939), your Radiographic Committee has been watching attentively developments concerning radiographic activities of technical organizations, such as the American Society of Testing Materials, and articles appearing in the technical press throughout the country. The committee likewise has maintained contact with the steel casting industry in order to ascertain the reaction and value of last year's questionnaire on the subject of Radiography. It is our belief that considerable interest has been manifested in the subject and a number of steel casting organizations have considered and used radiography for the first time this year.

In view of the fact that a majority of the members of this committee also are members of Committee E-7 on Radiography of the American Society of Testing Materials, and since the subject of Radiography is distinctly one falling under the auspices of this organization, it was decided that all work of an experimental nature be referred to the A.S.T.M. for their study, it being the distinct duty of your committee to report upon the progress of Committee E-7 of the A.S.T.M., as well as other developments incident to radiograph, which occurs throughout the country as a whole.

AMERICAN SOCIETY OF TESTING MATERIALS SESSION ON RADIOGRAPHY

There have been two important radiographic sessions held during the year. The first was held by the American Society of Testing Materials in June 1938, and contained four papers [1, 2, 3, 4] dealing with the subject.

Dr. H. H. Lester, in a paper[1] entitled "Radiography in Industry," presented first a rather generalized picture of radiography which was somewhat historical. He then proceeds to a discussion of the radiography of castings, and the following is abstracted from his paper:

"It was brought out in the 1936 Symposium, and again in the 1938 report to the A.F.A. Committee, that, in spite of obvious and admitted advantages, the makers of castings, with a few exceptions, are not using the method for development and control and are suffering financial losses in some cases due to the imposition of radiographic acceptance tests. It is a proper function of the radiographic committee to examine the causes for this situation and to suggest suitable remedies.

"It is pointed out that, in spite of its sixteen years of use, it remains relatively unfamiliar to and is held in suspicion by a large part of the foundry industry. There are reasons for this. It is unfamiliar because that industry has not found it absolutely necessary to use it. The author pointed out in a 1936 Symposium paper that radiographic tests may be applied to three general groups of castings: (a) those that are required to withstand high stresses; (b) those that, by virtue of the service they perform, must be very dependable; and (c) castings which require extensive machining. Other castings for special reasons outside of the above classifications may require radiographic study.

"These groups constitute only a small part of the tonnage of iron and steel foundries, most of which is made up of relatively small and structurally unimportant units.

"There is another group that could profit by X-ray development but because only a very few castings are made from a pattern, the cost of development cannot be absorbed easily. The manufacturer sees no economy in maintaining a radiographic plant for these special castings, and would hesitate anyway to undertake radiographic examination because if he charged development back to the customer his quotations would be so high that probably some one else would get the business. He does the next best thing. He manufactures as carefully as he can and takes a chance on X-ray acceptance tests — often to his final discomfiture.

"The above remarks refer mostly to cases where individual contracts are relatively small and to X-ray rather than to gamma-ray acceptance testing. Where large values are concerned, either because of the large number of castings or because of the large size of individual castings, the manufacturer does make profitable use of radiographic information

even though the tests may be performed by the customer. It is understood that manufacturers of navy castings have derived considerable benefit from radiographic studies made by naval inspectors.

"The foundryman is fearful of, or suspicious of, the tests partly because the tool is an unfamiliar one and partly because he has not been convinced that it is completely reliable. Mistakes have been made in interpretation and undue importance has been ascribed to relatively unimportant defects. These unhappy experiences have arisen quite largely if not altogether because of the fact that the radiography has been in the hands of the consumer and has been used to condemn poor castings rather than as a tool to construct good ones.

"The above remarks present a rather negative picture. There is, however, another point of view. For the quality casting, radiography or its equivalent is in the picture to stay because industrial evolution is creating an ever greater market for highly stressed and highly dependable structural units. Due to the competition of weldments and other casting substitutes, improvements in the quality of his ordinary product is necessary and the bid of these structures for the quality market forces the foundryman to defend it. Radiography becomes a logical tool that can be used in the struggle to retain his share of the business. It will be used by the manufacturer for his own benefit, rather than against him as it now often is in acceptance testing.

"There is a large problem in determining how radiography can be applied economically in the foundry. This will not be solved at once nor easily. It will require cooperative effort on the part of all interested. It would be a distinct help to industry if there were a special class, with appropriate subdivisions, set up for castings requiring high soundness characteristics. Standard radiographic specifications, acceptable to A.S.M.E., A.P.I., A.S.T.M. and A.F.A., should be worked out for this class. If this were done, those organizations supplying the products would no doubt make use of radiographic development. Committee E-7, working with the A.F.A., seems to be a logical place for the consideration of the problem.

"It appears that perhaps the greatest stumbling block in the way of utilization of radiographic testing in foundries is the cost. Considering the nature of the equipment and the vast sums spent in scientific and engineering development of it, the cost of X-ray apparatus is reasonable at present. There is no great likelihood that it will be much less expensive. Apparatus is only part of the capital investment. The total cost installed with needed accessory equipment may be double that of the

X-ray machine itself. The expense of operating adds considerable. But these costs represent only the expense of actually securing negatives.

"For the study of castings, particularly large ones, gamma-ray radiography seems to be very promising. There is needed very little investment in plant, a relatively small outlay for the rental of radium, and the technique of taking pictures is well understood, thanks to the excellent pamphlet of Briggs and Gezelius. It is possible for the small manufacturer to use gamma-rays where he could not afford to maintain an X-ray plant."

G. C. McCormick[5] presented a discussion of Lester's paper. He showed some of the relationships that exist between the service of high nickel alloy castings and the soundness of these castings as disclosed by radiographic examination. He also presented some notes on the use of radiography as a development tool in foundry technique.

A paper[2] on the secondary radiation of the radiography of aluminum, steel and lead was presented by H. E. Seemann. The paper is an outline of the principles of measurements and results of experiments performed to determine the amount of secondary radiation in the radiography of common industrial materials. Thicknesses were limited to those which can be radiographed conveniently without fluorescent intensifying screens. The principal conclusions drawn are: (1) that the proportion of secondary radiation from aluminum and steel increases almost linearly with thickness; (2) that lead screens may remove nearly one-half of the secondary radiation recorded when no screens are used; and (3) that no important reduction in secondary radiation is possible by adjustment of the kilovoltage within the range it is necessary to use for a given subject.

In a paper[3] on gamma-ray radiography, G. E. Doan and S. S. Young undertook a study to refine the accuracy of radiographic testing. In gamma-ray radiography, dependable registry may be obtained from the penumbral shadow, the formula developed permitting a calculation of the minimum distance permissible in obtaining certain registry. At very short distances, such as those that form a vertex angle of ten ($10°$) degrees or more between source and flaw, registry by penumbral shadow becomes undependable, unless the flaw lies very close to the film. Sharp shadows were obtained at $14°$ in source-to-flaw distance with a radiation source

of $\frac{1}{8}$ in. in diameter and at 20 in. with a $\frac{1}{4}$ in. diameter source. In these cases, the source and flaw subtend a common vertex angle of about 2 degrees. This result indicates the superiority of a small source in gamma-ray testing.

The fourth paper[4] was entitled "A Study of Intensifying Screens for Gamma-Ray Radiography," by C. W. Briggs and R. A. Gezelius. These authors exposed a number of different types of calcium tungstate intensifying screens to gamma-rays and from the resulting film densities they prepared exposure charts. It was found that, when compared to the standard lead-foil intensifying screens, the calcium tungstate screens reduce the exposure time considerably. However, the intensity does not vary according to the inverse square law and the sensitivity or definition cannot equal that which may be obtained with the lead-foil screens.

INSTITUTION OF ELECTRICAL ENGINEERS SESSION ON RADIOGRAPHY

The second interesting session on radiography was presented by the Institution of Electrical Engineers (British)[6] during a discussion on "Non-Destructive Testing" held in November 1938 in England. The three papers containing information on radiography were:

(1) "Radiography—An Aspect of Non-Destructive Testing," by V. E. Pullen

(2) "Industrial Radiography in the Continent of Europe," by J. E. DeGraaf

(3) "Non-Destructive Testing in the U.S.A.," by H. H. Lester, R. L. Sanford and N. L. Mochel

The various methods and the equipment used in Europe, England and the United States were very carefully considered. The American paper is a very excellent resume of the entire subject of non-destructive testing by three well-known authorities.

PROGRAM OF A.S.T.M. COMMITTEE E-7

It was explained in last year's report that E-7 of A.S.T.M. had been divided up into six subcommittee groups, one of which (subcommittee 1) was instructed to study radiography of cast metals. During the past year, a program of study was prepared and subcommittees appointed to carry forward the work. The program includes:

(1) To revive committee E 15-29 on "Radiographic Testing of Metal Castings."

(2) To prepare information as to the types of work which radiographic examination is applicable and the advantages, disadvantages and limitations of radiography as applied to castings.

(3) Prepare illustrations of various types of defects that may be encountered in castings.

(4) Work on improving and establishing the technique of radiography, including (a) information on film density and distance of source to films; (b) requirements of a satisfactory film and what conditions affect obtaining a satisfactory film; (c) qualification of operators; (d) type of sensitivity gauges; and (e) general information on technique so that a beginning operator may proceed under a recognized procedure.

(5) Prepare a set of radiographs which show casting conditions that may be interpreted as (a) acceptable; (b) defective but repairable by welding; (c) rejected. In this work due consideration, of course, is to be given to the purpose for which the castings are intended.

(6) Prepare standard specifications for radiographic examination.

The one other important development in radiography during the year is the issuing by the Navy Department of "Gamma-Ray Radiographic Standards of the Bureau of Engineering for Steel Castings for Steam Pressure Service." These standards illustrate types of defects that may occur in the castings and state whether they are acceptable, rejectable or may be repaired by welding. These standards have been issued to comply with information on rejection standards in connection with the Navy Department Specification 49Slj.

After hearing these standards presented and discussed at a session at the 1939 Cincinnati Convention of A.F.A., by N. A. Kahn, Materials Laboratory, New York Navy Yard, who was responsible largely for assembling the various radiographic films, your Committee believes that the Gamma-ray Radiographic Standards of the Bureau of Engineering for Steel Castings for Steam

Pressure Service are imminently fair and reasonable inspection standards applicable to steel castings for Navy steam pressure service and comparable industrial use.

Respectfully submitted,

Committee on Radiography

C. W. BRIGGS, *Chairman*

E. J. ASH   P. E. McKINNEY
FRED GROTTS   J. J. CURRAN
L. C. WILSON   E. W. PAGE

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5—G. C. McCormick, "*Some Pros and Cons of Radiography*," A.S.T.M., BULLETIN No. 95, Dec. 1938, p. 25.

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DISCUSSION

Chairman: J. W. BOLTON, Lunkenheimer Co., Cincinnati, O.

Co-Chairman: W. C. HARTMANN, Bethlehem Steel Co., Bethlehem, Pa.

NOTE: *Following the presentation of the committee report on Radiography by Mr. Briggs, N. A. Kahn, New York Navy Yard, presented the "Gamma-Ray Radiographic Standards of the U. S. Navy for Steel Castings." As these standards consist of radiographs of large size, requiring special printing technique, it is planned to reproduce Mr. Kahn's report as a special publication. Accordingly, it is omitted from these proceedings.*

CHAIRMAN BOLTON: We are very indebted to Mr. Briggs, for the clear presentation of the committee's report, and to Mr. Kahn, for the

detailed presentation of the radiographic standards of the U. S. Navy for steel castings. Without doubt, a great many of us will give it a great deal of study as soon as the material is printed.

Co-CHAIRMAN HARTMANN: A question I would like to have answered is—"Has the Bureau of Engineering of the Navy adopted the same standards or do they contemplate adopting them?"

W. J. JEFFRIES[1]: In answer to Mr. Hartmann's question, I can say, "Yes." Mr. Kahn and Mr. Briggs' committee are entitled to a great deal of credit for this presentation this morning. We think this is an excellent way to bring out the hazards in castings in which we are particularly interested. As stated by Mr. Kahn, these standards are the standards of the Bureau of Engineering and not of the Navy Department. The reason for that is until a specification is approved by all the Bureaus of the Navy Department it is not a Navy Department specification. However, any Bureau is permitted to use a tentative standard prepared by another Bureau. These particular standards are in that category.

I am quite confident these standards will ultimately be accepted by the Navy Department Specifications Board and will become Navy Department Specifications. In the meantime, the Bureau of Construction and Repairs does use these standards, with this reservation, however. There is a significant difference between a defect in the castings used under high steam pressure and the defects found in the castings used for structural purposes. We are interested principally in structural castings. Therefore, there may be certain defects in a casting that would be acceptable to us but not to the Bureau of Engineering. For example, in a long casting having sufficient width and thickness, if the casting is subject to compression or even though the casting is stressed in the direction in which the defect occurs, then the defect if axially positioned merely converts the solid form into a tubular form in which shape it is usually acceptable for construction purposes.

Mr. Kahn pointed out the very significant advancements of radiography in connection with the salvage of castings. When we take a rolled shape and weld it, we have in that part which is welded, essentially a casting. There is no logical reason why we can't take a casting so made and take some part of it away by chipping or other means of removal and redeposit new metal, but it is still a casting. If subsequent radiographic examination discloses that the cast metal, in the form of welding material, has been properly applied to the defect and that the defect is cured or eliminated, there is no reason why that casting should not be considered of equal integrity to the solid casting which would require no repairs.

So that, in the application of radiography to navy work in general, there has been an opportunity given the casting manufacturer to weld

[1] Senior Materials Engr., Bureau of Construction and Repair, Navy Department, Washington, D. C.

a casting which with less careful consideration of the defect he might permanently reject. The work that has been done by the Navy Department therefore, I think, has been a distinct service to the casting manufacturer and I personally advocate radiography.

As many know, there has been a great deal of opposition from the casting industry to radiography. Mr. Kahn's paper brings out the significant advances of the application of radiography and I hope it will be received in the same spirit in which it is presented, that is, with the object of assisting the industry as far as possible.

I would like to make one further remark. Perhaps Mr. Kahn forgot it or does not want to mention it, as to the availability of these standards. There have been many requests for them. I admit that there has been a great deal of difficulty considering the reproducibility of the photographs— however, Mr. Kahn has produced some very nice prints which we think will reproduce in half-tone. The difficulty was in reproducing these prints so that sufficient detail would be brought out, but they will, however, ultimately be printed.

Just how they will be distributed we do not know. It is an expensive job and the preparation of a limited number of sets was quite costly. The distribution of these sets has been limited to the activities of the Navy Department that were primarily concerned with their use. Many requests that have been received for copies of these standards have been denied because of an insufficient number of copies available.

They are available for inspection, however, at all Navy Yards or Bureaus or at the Inspector of Machinery and the Superintending Constructor at the various ship-building yards. If anyone desires to examine these standards, they can do so if they apply to these particular offices. No doubt, they will ultimately be published in some form.

If in publishing these illustrations they can be reproduced with the visibility Mr. Kahn has in the prints, I think that would be a marvelous way to publicize the data. May I add, however, the original radiographs do present a better medium of study and we would be glad to show the original radiographs to anyone interested.

CO-CHAIRMAN HARTMANN: I think Mr. Kahn and the Bureau of Engineering are to be commended on this excellent report they have prepared in setting up these standards. This is my first opportunity of seeing the standards and I was particularly impressed by the last few photographs where they digressed from the casting and really showed us what we could expect from film defects.

Report of the Technical Director, Foundry Sand Research Committee

Members of the American Foundrymen's Association:

The chief work carried on under the auspices of the Sand Research Committee during the past year has been that of Sub-Committee 6b7, dealing with the behavior of steel sand mixtures when exposed to high temperatures. The results of this work are reported elsewhere* by D. L. Parker, chairman of the sub-committee and H. L. York, Research Assistant. All that need be said here is that the experiments have involved a large amount of careful work, and the results obtained are most interesting.

Flowability and Durability

Two important problems which the committee has before it are the development of satisfactory tests for determining the flowability and durability of sand. These were assigned to two sub-committees, and they have not reached a point where it is possible for them to make a report. Needless to say these two problems are difficult ones to solve.

Revisions of Standard and Tentative Standards of Tests

Under the heading of "Molding Sand Purchase Forms," on page 83 of the fourth edition of "Testing and Grading Foundry Sands and Clays," there are given tolerance limits for the several properties, and although a footnote on that page states that: "The tolerances given are only suggested, and may be adjusted by agreement between producer and consumer," some objection has been raised to suggesting any tolerances whatever.

The committee therefore recommends that these tolerances be omitted, and that the footnote be revised to read: "All allowed tolerances are to be adjusted by agreement between producer and consumer."

Some criticism has been raised against the grain fineness classification on page 103, it being claimed by the non-ferrous group, for example, that classes No. 1 and No. 2 were too broad.

If these classes were subdivided, other groups might demand subdivisions of any of the others.

The committee recommended that attention be called to the fact that no consumer is under any obligation to order sand by grain class number, and can, if he so desires, state the grain fineness number, or range of grain fineness which he desires.

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*"Progress Report on Investigation of Effects of High Temperatures on Steel Sands." by York and Parker. See pp. 805 to 830.

At the back of the Handbook on testing, there is a glossary of terms used in foundry sand work. It has been found that with the development of our methods of testing, there was a need for additional terms to express certain properties. This applied particularly to the testing of sand at high temperatures.

In order to meet this need a sub-committee has been appointed to recommend and define necessary terms.

Respectfully submitted,
H. Ries, *Technical Director, Foundry Sand Research Committee*

Progress Report on Investigation of Effects of High Temperatures on Steel Sands*

Foreword

In the fall of 1936, the Steel Division of the American Foundrymen's Association requested the Committee on Foundry Sand Research to initiate a study of methods of testing properties of sands at the temperatures encountered in actual practice. This request was made as it was realized that while methods of testing and control at room temperatures have been quite thoroughly developed by the Committee, it had become increasingly evident that a most important factor in sand control is its behavior at elevated temperatures and that a knowledge of how to test at these temperatures is imperative.

Acting on this request, the Foundry Sand Research Committee through a special sub-committee outlined a research program which together with an appropriation for initiating the investigation was approved by the A.F.A. Board of Directors. The investigation was started at Cornell University, H. L. York, a qualified technical graduate with practical foundry training, being engaged as research assistant to work under the immediate supervision of Dr. H. Ries, technical director, A.F.A. Foundry Sand Research Committee and Prof. A. C. Davis, Head of Experimental Engineering Department, Cornell University, collaborating with an A.F.A. Advisory Committee of steel foundrymen and sand technologists as follows:

Sand Research Sub-Committee 6b7 on Physical Properties of Foundry Sands at Elevated Temperatures

Chairman, D. L. Parker, Foundry Research and Test Division, General Electric Co., West Lynn, Mass.

C. W. Briggs, Tech. Advisor, Steel Founders' Society of America, Cleveland, O.

A. C. Davis, Head, Dept. of Experimental Engrg., Cornell University, Ithaca, N. Y.

H. W. Dietert, Pres., Harry W. Dietert Co., Detroit, Mich.

Werner Finster, Met., Reading Steel Casting Div., American Chain & Cable Co., Reading, Pa.

W. C. Hamilton, Res. Director, American Steel Foundries, E. Chicago, Ind.

Howard Mason, Gould Coupler Co., Depew, N. Y.

H. D. Phillips, Lebanon Steel Foundry, Lebanon, Pa.

C. P. Randall, Chemist, Hunt-Spiller Mfg. Corp., Boston, Mass.

W. G. Reichert, Fdry. Met., American Brake Shoe & Foundry Co., Mahwah, N. J.

D. C. Zuege, Tech. Director, Sivyer Steel Casting Co., Milwaukee, Wis.

Under the direction of this committee the work has been carried on with considerable time having been devoted to the development of a furnace and test apparatus suitable for making the tests under high temperature conditions. While progress reports have been presented before sessions of the annual conventions of the Association this present published report brings to the members of the Association the first published data as secured in such form that its application to general practice can be studied and used.

As to the practical value of the work, attention is directed to the introduction of this report as prepared by the committee chairman, D. L. Parker.

In financing this investigation, as in the case of the previous work on sand testing, the Association has made appropriations from its general fund of $3,225.00 and has sought and received in addition contributions from some 65 steel foundries and foundry supply firms to the amount of $2,720.00. Also the work has been aided greatly by contributions of equipment and directional service from the experimental engineering department, Cornell University. These contributions and the services of Dr. Ries and Prof. Davis are gratefully acknowledged by the Association.

The initial work of the investigation is scheduled for completion in the spring of 1940 but the committee believes that further work of the greatest value to all types of foundries can be developed through this cooperative investigation if funds are made available. For this purpose the Association is soliciting further contributions.

Introduction

BY D. L. PARKER*, GENERAL ELECTRIC CO.
SCHENECTADY, N. Y.

To those of us engaged in the manufacture of steel castings, the following "Report of Progress of Sand Research on Steel Sands at Elevated Temperatures" by H. L. York, should be of extreme interest to both the practical and technical foundrymen. It opens an entirely new field of thought pertaining to sand mixtures and properties. The "Hot Strength Committee" feels that the information contained in this report will be of assistance in the development of better methods of compounding sand mixtures to meet the actual conditions that develop in the casting of molten metal.

A practical example comes to mind that occurred during the preparation of this statement which, I believe, is well to summarize, in that hot strength properties, if available, would aid greatly in helping to solve the problem:

Sand mixture "A," composed of silica sand, silica flour, bentonite and core oil, is used as a facing on turbine castings from 5000 to 40,000 lbs. in shipping weight, in addition it is also used on certain other work, about $1\frac{1}{2}$ in. average thickness with the castings having numerous T and L sections. It is desired to compound a mixture "B" having the same properties with the exception that it will be more collapsible thus facilitating the production of these castings with a minimum of "hot tears." In order to accomplish this, the bentonite content was materially reduced and some core oil taken out, a dry binder was added together with a small amount of cereal for green strength. The following physical properties were obtained:

	Mix "A"	Mix "B"
Moisture (Per Cent)	8.0	8.0
Flowability	77.0	82.0
Green Permeability	40.0	38.0
Dry Permeability	61.0	58.0
Green Comp. Strength (lb. per sq. in.)	10.9	8.2
Dry Tensile Strength (lb. per sq. in.)	125.0	120.0

* Chairman, Sub-Committee 6b7, Hot Strength Research on Steel Foundry Sands, A. F. A. Committee on Foundry Sand Research.

One can readily see that with the exception of green compression and flowability there is little to be gained in comparing the results, yet from practical experience we know that mixture "B" should be much more collapsible. It is my contention that if these two facings were subjected to hot-strength tests involving expansion-contraction, compression and collapsibility, one would know exactly what to expect in regard to hot-tearing.

Summarizing the progress to date of the "Hot Strength Research" being carried on at Cornell University, it is safe to say that the first positive results are now being obtained after many months of concentrated activity involving the development of a furnace and testing technique. With the programs as outlined at two Committee meetings, held prior to the 1939 Cincinnati Convention of A. F. A., there should be definite and comprehensive data available for dissemination to the industry in the very near future pertaining to *hot strength properties of steel foundry sand mixtures.*

It has been both a pleasure and privilege to have worked together with the "Hot Strength Committee" and our Cornell University associates. As chairman of this committee I wish to thank them both for their co-operation and effort during the last few years in helping to develop a new concept of sand properties.

Acknowledgment

Report of Progress of Sand Research on Steel Sand Mixtures at Elevated Temperatures

BY H. L. YORK,* ITHACA, N. Y.

Program

The program of sand research was formulated by Sub-Committee 6b7 on Steel Sands, of the Foundry Sand Research Committee of the American Foundrymen's Association. The committee directed that certain sand mixtures be tested, specified the sands and binders to be used, the proportions in which they were to be mixed, and the exact method of test procedure.

Object of Tests

The object of the tests was to determine the behavior of certain sand mixtures at elevated temperatures, and to acquire information which could be used as a guide in future investigations.

Sand Mixtures

The committee originally specified that a number of sand mixtures be tested including brass sands, gray iron sands and steel-sands. After making preliminary tests of some of these mixtures, it was found that the program was too comprehensive. It was then decided to concentrate on certain steel-sand mixtures.

The mixtures finally selected included four silica sands bonded with fireclay, the same four sands bonded with bentonite, and one natural molding sand, the bond of which was reduced by adding Portage No. 5 sand. Table No. 1 shows the character of the sands selected.

Preparation of Specimens

Mixtures were made in a No. 0 Simpson muller, and the standard A. F. A. 2-in. test specimen baked at 110°C. (230°F.) for 2½ hrs. was used in making all the tests. Baked specimens were kept stored over calcium chloride in a large dessicator. In so far as it was possible, the specimens were prepared and tests made in accordance with the methods prescribed in the A. F. A. test code as published in "Standards and Tentative Standards for Testing and Grading Foundry Sands and Clays."

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* Research Fellow, Cornell University.

Table 1

BASE MATERIALS

Sand No.	1	2	3	4	6
Material Name	Ottawa Crude	Portage	½ No. 30 Fines Cut ½ No. 424 Washed Sand	Washed Silica Sand	South Jersey Molding Sand
Grade	Utica Crude	No. 5	Mixed	No. 80	M.M.—35
Type	Rounded	Angular	Sub-Angular	Sub-Angular	Rounded to Sub-Angular
Screen Analysis					
On 6	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.08	0.00	3.20
20	0.04	3.12	1.24	0.02	7.20
30	5.68	12.82	9.86	0.68	10.80
40	50.13	32.58	25.00	2.98	13.60
50	31.73	25.40	31.38	11.20	23.80
70	7.23	13.02	19.68	27.62	14.80
100	3.35	8.32	9.90	37.40	5.60
140	1.56	3.54	2.18	13.22	0.80
200	0.55	0.86	0.56	4.84	0.50
270	0.22	0.08	0.06	0.88	0.30
Pan	0.26	0.26	0.04	0.30	0.40
A. F. A. Fineness No.	38.1	41.0	42.13	69.0	35.0
Clay	.....	.....	.....	.....	19.0

Other Materials (Binders Etc.)
1. Bentonite
2. Fireclay

All mixtures were tested for green and dry permeability and green and dry compression strength.

Test Furnace

A gas-fired furnace designed and constructed in the laboratory at Cornell was used in making the tests.

The furnace (Fig. 1) consists of a combustion chamber (A), and a testing chamber (B). A gas burner (C) is mounted in an inverted position over the combustion chamber. The products of combustion pass from the combustion chamber through a flue into the testing chamber where they move upward around an alundum core in which the specimen to be tested is placed. The furnace heats very uniformly and is easily controlled.

HIGH TEMPERATURE TESTS
Compression Tests

Compression tests were made to determine the strength of the mixtures at various temperatures. Two types of tests were carried out: (1) slow heating tests, and (2) shock tests.
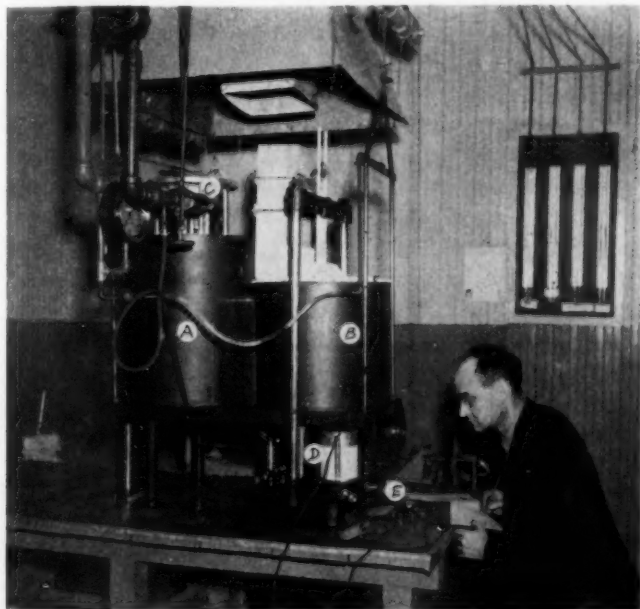
FIG. 1—GAS-FIRED TEST FURNACE. *A*, COMBUSTION CHAMBER; *B*, TEST CHAMBER: *C*, GAS BURNER; *D*, LOADING DEVICE; *E*, RECORDER.

Slow Heating Tests

The true compression strength of the sand mixtures at various temperatures was determined by testing specimens which had been heated at a rate of 3°C. (5.4°F.) per minute. The specimens, after having been heated to the desired temperature, were left in the furnace for 35 minutes at that temperature before testing. It was found necessary to conduct tests in this manner in order that the specimens would be baked* uniformly throughout.

Shock Tests

The effect of "heat shock" on the sand mixtures was determined by placing specimens in the furnace which had been previously heated to the desired temperature. The specimens were then left in the furnace for time intervals varying from two minutes to that necessary for the development of a constant strength.

Each of these tests represents conditions that exist in a mold at the time of casting. The sand on the face of a mold is subjected to heat shock; that back from the face is heated more slowly.

Temperature Intervals of Tests

Tests were made at intervals of 150°C. (302°F), starting at 300°C. (572°F.). Additional tests were made to determine the true form of the curves in the vicinity of maximum strength and in the plastic range. All tests were made in duplicate, and in case the results did not check within 10 per cent, the test was repeated until checks were obtained. Some tests were repeated as many as six times.

Properties of Sand Mixtures at Elevated Temperatures

The influence of heat on the sand mixtures tested is best shown by a discussion of the data presented in graphic form. These data show that some mixtures are affected by shock while others are not.

Curves of a sand mixture that is not affected by shock will be discussed first, and test No. 2C (Fig. 2) illustrates the behavior of such a sand mixture.

The curves at the left of the figure show the relationship between strength and time at various temperatures for specimens which were subjected to shock. The slope of the curves indicates the rate of rise in strength as the specimen is progressively heated

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* The term baking refers to the exposure of the sand to temperatures above 110°C. (230°F.). American Foundrymen's Association, *Standard and Tentative Standards for Testing & Grading of Foundry Sands and Clays*, 4th Edition, 1938, P. 161.
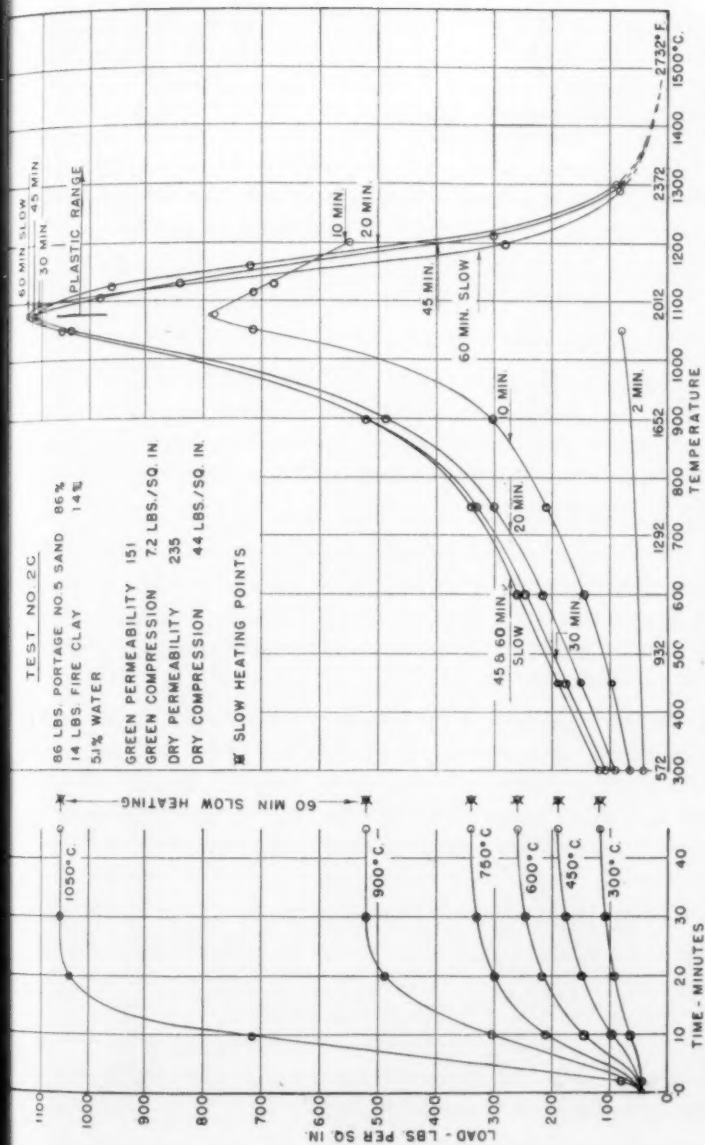
FIG. 2—CURVES TYPICAL OF A SAND MIXTURE NOT AFFECTED BY TEMPERATURE-SHOCK. THE CURVES AT LEFT SHOW THE RATE OF BAKING AT DIFFERENT TEMPERATURES AND THE CORRESPONDING COMPRESSION STRENGTH. ABSENCE OF SHOCK EFFECT IS SHOWN BY IDENTICAL STRENGTHS UPON HEATING SLOWLY AS COMPARED WITH SUDDEN EXPOSURE TO THE TEST TEMPERATURE. THE CURVES AT THE RIGHT SHOW THE STRENGTH ATTAINED BY THE SAND SPECIMENS AFTER EXPOSURE AT A CERTAIN TEMPERATURE FOR VARIOUS TIME INTERVALS. THE BOND PARTIALLY FUSES AND IS PLASTIC BETWEEN 1075°C. AND 1300°C. (1967°F. AND 2372°F.). THE BOND ACQUIRES A GLASSY APPEARANCE AT 1300°C.

to the center. When the specimen is baked uniformly throughout, the strength becomes constant.

The time required for a specimen to develop its maximum strength depends upon the temperature to which the specimen is exposed. This time varies from thirty-five minutes at 300°C. (572°F.) to ten minutes at 1050°C. (1922°F.).

If the completely baked specimen which had been subjected to shock shows the same strength as the one which was slowly heated to the test temperature, the sand was unaffected by shock.

The points not connected to the curves and designated as "slow heating" represent the strength of the sand when heated, at the rate of 3°C. (5.4°F.) per minute, to the test temperature.

The curves at the right, up to the point indicating the maximum sand strength, were derived from the curves on the left. The points for higher temperatures were obtained from test data. These curves show that the sand gains strength with a rise of temperature until the maximum strength is reached.

If the temperature is raised beyond that corresponding to maximum strength, the strength drops off rapidly to about 50 p.s.i. At still higher temperatures, the strength drops slowly until it reaches zero at the temperature at which the specimen slumps under its own weight.

The drop in strength, at temperatures above the temperature of maximum strength, is due to progressive fusion of the bond. The bond becomes plastic, and deformation under pressure is pronounced. The temperature range in which the sand specimens exhibit properties of plasticity under pressure may be called the "plastic range."

The plastic range may be divided into two stages. In the first stage, the bond becomes plastic, but shows no visible signs of fusion. This stage of the plastic deformation is illustrated by the descending portion of the curve between the temperature of maximum strength and the temperature at which the strength begins to drop very slowly. The behavior of the specimen in this temperature range indicates that the bond is partially fused.

In the second stage, which is shown by the lower part of the curve, the bond is completely fused, and in this condition it behaves as a viscous liquid.

It should be observed that the 60-minute slow heating, the 45-minute shock and the 30-minute shock-test curves at the right are practically identical. Since one of these curves represents the behavior of the sand mixture under slow heating and the other two under conditions of temperature-shock, it should be obvious that the sand was not affected by shock. The spread of these curves, beyond the point of maximum strength, is due to the progressive fusion of the bond with time. The specimens which were heated slowly developed a strength below that of the specimens exposed to shock heating because the additional time allowed for the slow heating permitted fusion of the bond to progress to an extent not obtainable in the shorter time allowed for shock-tests.

Another sand mixture which was not affected by temperature-shock is shown in Figure 3.

Curves of a sand mixture that is affected by temperature-shock will now be discussed. The curves of test No. 4C (Fig. 4) are typical of a sand mixture affected by temperature-shock.

The effect of temperature-shock, on sand mixtures susceptible to it, is to produce cracks in the specimen, as shown by the specimen illustrated in Fig. 5, which cracked without being loaded.

The effect of cracking is to reduce the strength of the specimens. The compression strength for the shock-test curve in Fig. 4 could not be determined at temperatures above 600°C. (1112°F.), because of the shattering of the specimens when exposed suddenly to the test temperatures above that point.

It should be observed that the shock-test curve at the left in Fig. 4, showing the strength-time relationship at 600°C. (1112°F.), indicates a strength of 115 lb. per sq. in. for the specimens heated 35 minutes, and a strength of 144 lb. per sq. in. for the specimens heated slowly from room temperature to 600°C. (1112°F.) and held at that temperature for 35 minutes. The difference in strength is due to the formation of small cracks in the specimens which were subjected to shock-tests at the temperature of 600°C. (1112°F.).

If the sand mixture represented in Fig. 4 had not been susceptible to temperature-shock, the 35-minute shock-test curve would have been identical with the 35-minute slow-heat curve.

Figs. 6, 7 and 8 were obtained from other sand mixtures which were severely affected by temperature-shock and which behaved in a manner similar to that of the mixture discussed in Fig. 4.

FIG. 5 —A SAND MIXTURE NOT AFFECTED BY TEMPERATURE-SHOCK. THE DESCENDING PORTION OF THE CURVES AT THE RIGHT SHOW THAT SPECIMENS UNDERGO PROGRESSIVE FUSION IN THE PLASTIC RANGE AND, FOR A GIVEN TEMPERATURE, THE STRENGTH IS DEPENDENT UPON THE TIME OF EXPOSURE.
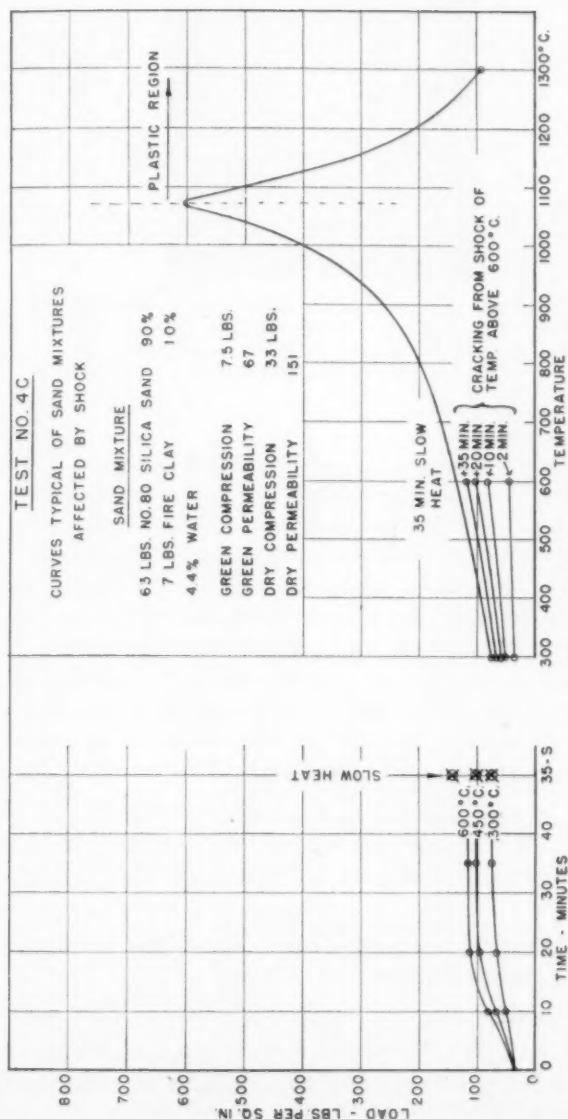
FIG. 4—THIS MIXTURE DID NOT WITHSTAND THE SHOCK TESTS AT 600°C, (1112°F.). THE TRUE STRENGTH AS SHOWN BY SLOW HEATING IS 600 LB. PER SQ. IN.
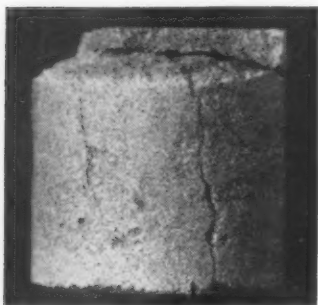
FIG. 5—No. 80 SILICA SAND WITH 3.3 PER CENT BENTONITE AND 1.5 PER CENT WATER. THE
SPECIMEN SHOWS THE RESULTS OF TEMPERATURE-SHOCK AFTER EXPOSURE AT 750°C. (1382°F.)
FOR TWO MINUTES. NO LOAD WAS APPLIED. THE LIGHT-COLORED SHELL SHOWS THAT BAKING
WAS NOT UNIFORM THROUGHOUT.

It is possible, in some cases, to obtain check results on compression strengths even though cracking from temperature-shock occurs. The curves in Fig. 9 illustrate such a case. The curves at the right show that slow heating tests are necessary to determine the true sand strength. The points obtained from the shock-tests produce smooth curves which conform in general shape to the curves to be expected for a low-strength sand mixture not affected by temperature-shock. It is only by comparison with the strengths developed by slow-heating that it is possible to determine the effects of temperature-shock in this sand mixture. The specimens developed very small cracks upon exposure to temperatures above 450°C. (842°F.).

Removing a specimen from the hot furnace for the purpose of examination for cracking is not desirable, because sudden cooling may produce cracks which were not present when the specimen was in the furnace.

Fig. 10 represents a sand mixture which was but slightly affected by temperature-shock.

It was observed that some sand mixtures cracked when heated at a rate of 3°C. (5.4°F.) per minute. If cracking occurs on slow heating, the rate of heating should be reduced until the specimens are no longer affected. The erratic behavior of a sand which cracked on slow heating is shown in Fig. 11. The scattered points, through which the curve was not drawn, were obtained by slow heating. This sand mixture should develop its maximum strength at about
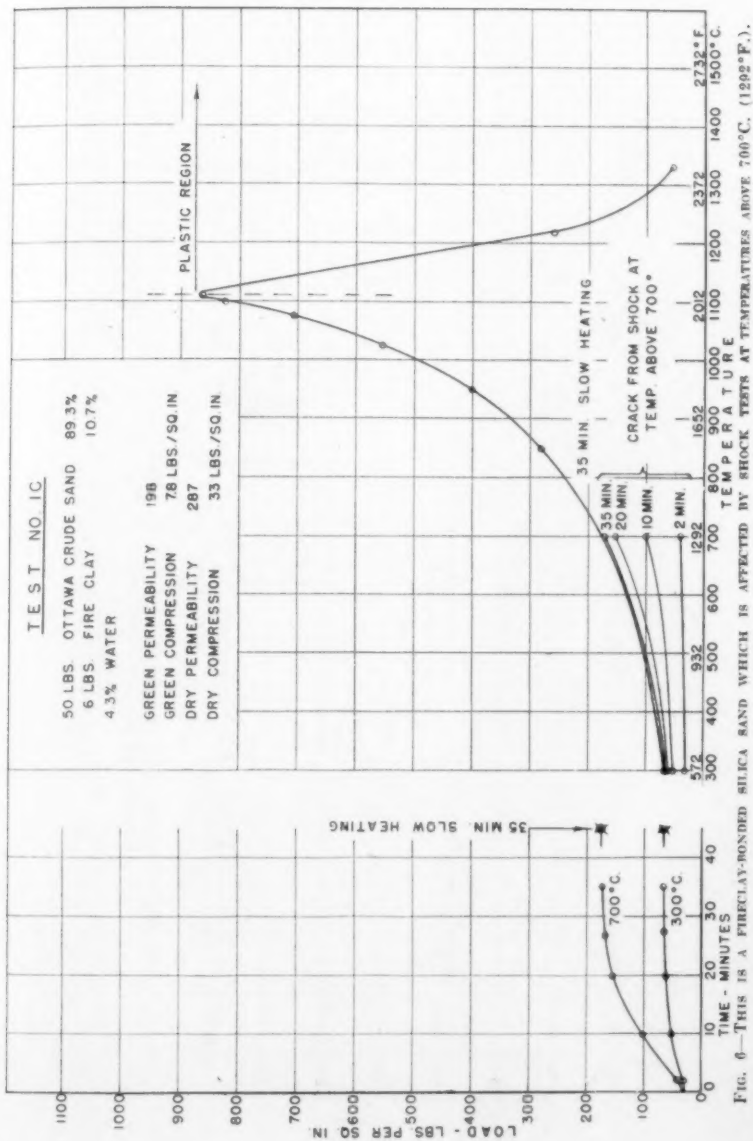
FIG. 6.—THIS IS A FIRECLAY-BONDED SILICA SAND WHICH IS AFFECTED BY SHOCK TESTS AT TEMPERATURES ABOVE 700°C. (1292°F.).
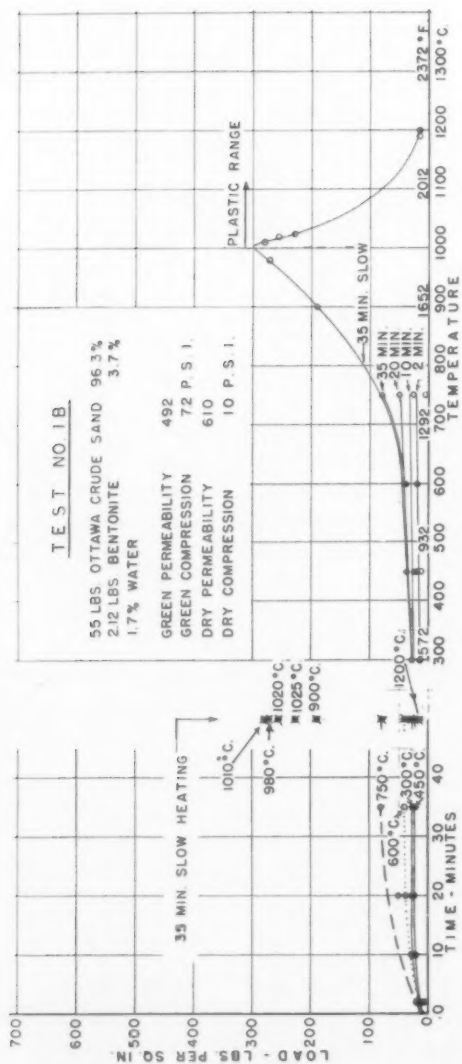
FIG. 7—ANOTHER MIXTURE WHICH IS AFFECTED BY SHOCK TO SUCH AN EXTENT THAT IT IS IMPOSSIBLE TO MAKE STRENGTH DETERMINATIONS ABOVE 750°C. (1382°F.).
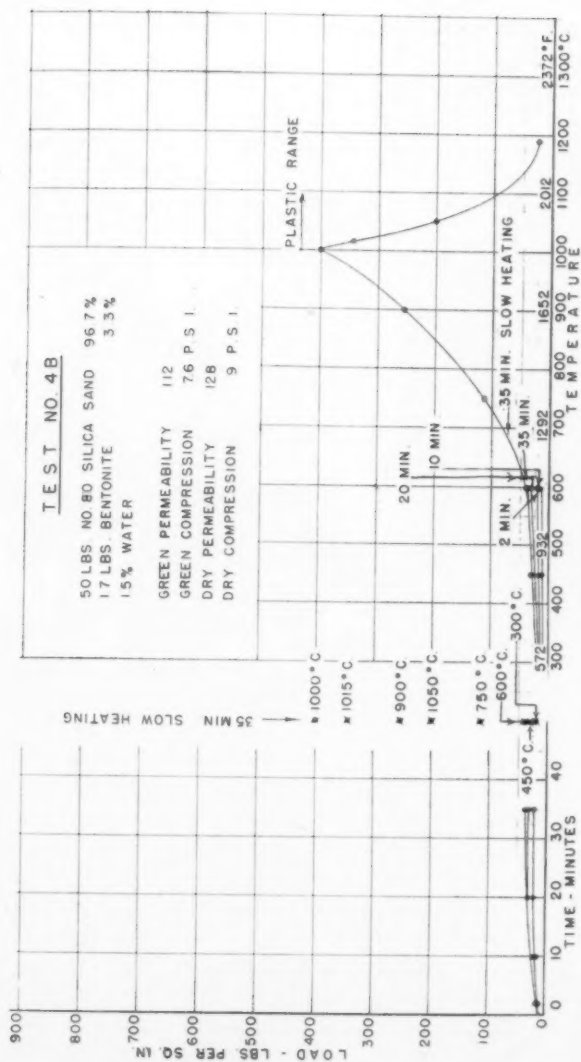
FIG. 8—THIS MIXTURE SHOWS THE EFFECTS OF SHOCK TESTS AT TEMPERATURES ABOVE 600°C. (1112°F.). THE SPECIMEN SHOWN IN FIG. 5 WAS MADE OF THIS MIXTURE.
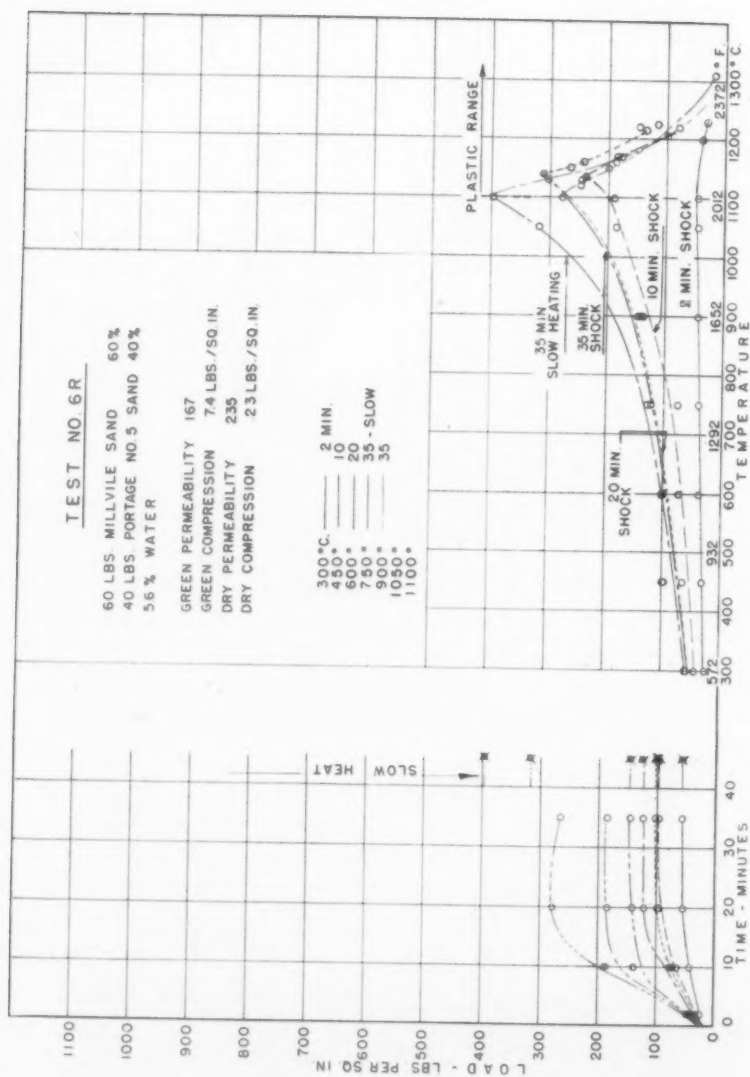
FIG. 9—THIS MIXTURE CONTAINS 11.4 PER CENT A.F.A. CLAY, WHICH IS AN INGREDIENT OF THE MILLVILLE GRAVEL. ALL SPECIMENS CRACKED WHEN EXPOSED TO A SHOCK TEST AT APPROXIMATELY 450°C. (842°F.), AND CONSEQUENTLY SHOW A LOWER STRENGTH THAN WAS OBTAINED BY SLOW HEATING.
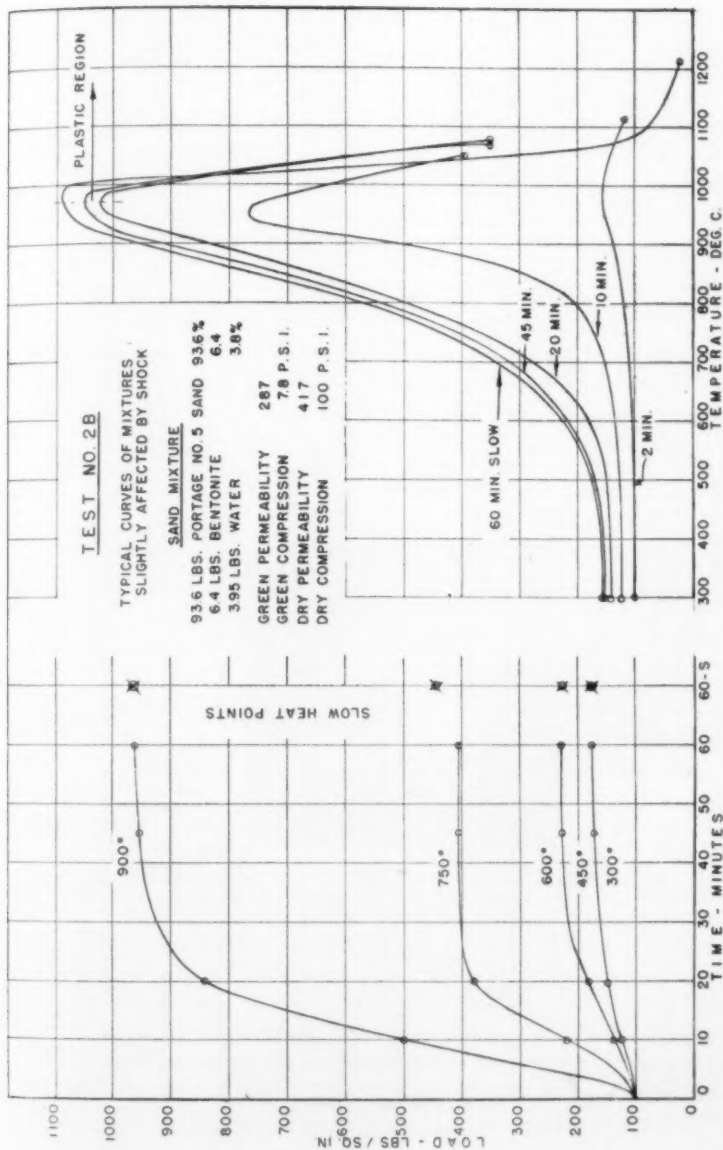
FIG. 10—THE SLIGHT EXTENT TO WHICH THIS SAND-CLAY MIXTURE WAS AFFECTED BY SHOCK IS SHOWN BY THE SMALL DIFFERENCE IN STRENGTH BETWEEN SPECIMENS SUBJECTED TO SHOCK HEATING AND THOSE HEATED SLOWLY. THIS IS THE ONLY MIXTURE TESTED WHICH DID NOT SHOW A SHARP PEAK AT THE POINT OF MAXIMUM STRENGTH.
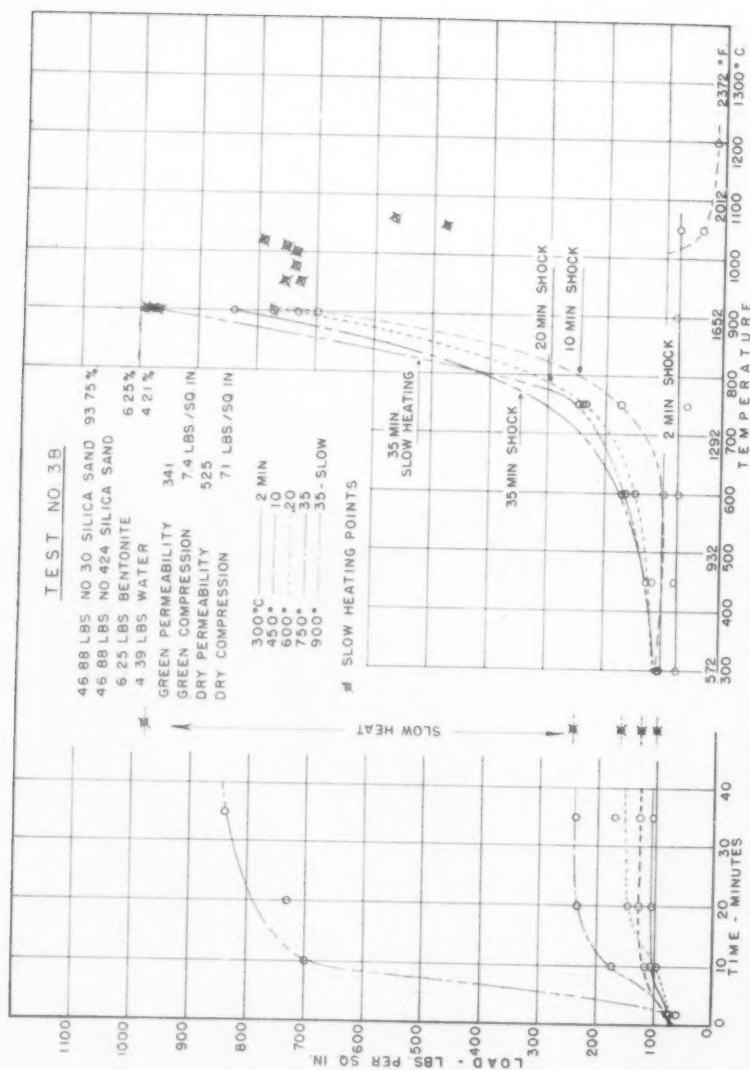
FIG. 11—THIS IS A SAND MIXTURE WHICH IS AFFECTED BY SHOCK WHEN HEATED AT 8°C. (5.4°F.) PER MINUTE. THE SPECIMEN MADE OF THIS MIXTURE CRACKED AT 600°C. (1112°F.), WHICH PREVENTED THE DEVELOPMENT OF THE NORMAL STRENGTH AT HIGHER TEMPERATURES. THE SCATTERING OF THE POINTS AT THE RIGHT WAS CAUSED BY THE CRACKING OF THE SPECIMENS, THUS MAKING IT IMPOSSIBLE TO CONSTRUCT THE DESCENDING PART OF THE CURVE.

1000°C. (1832°F), but failed to do so because of cracking at a low temperature (about 600°C.).

Character of Failure of Sand Specimens Under Load

If a sand is not affected by temperature-shock, and if it is tested at a temperature below that of maximum strength, the specimen will fail on shear planes with a conical-shaped fracture. A typical conical fracture is shown in Fig. 12. If the fracture is not conical, the specimen either cracked from temperature-shock, was defective, or was eccentrically loaded.

At temperatures above that corresponding to maximum strength, the sand specimens mash or deform permanently under load. The bond undergoes progressive fusion in this temperature range and the specimens become somewhat plastic. They do not collapse, but become barrel-shaped and crack in circumferential tension. Figs. 13 and 14 show the behavior of a sand bonded with fireclay and tested at 1200°C. (2192°F.) and at 1300°C. (2372°F.) respectively.
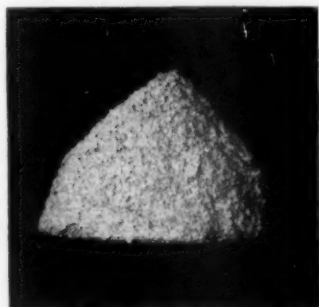
FIG. 12—A TYPICAL CONICAL FRACTURE. THE FLATTENED SURFACE AT THE UPPER LEFT IS DUE TO ABRASION IN HANDLING. SPECIMEN: PORTAGE No. 5 SAND WITH FIRECLAY. HEATED 45 MINUTES AT 750°C. (1382°F.). BREAKING LOAD 300 LB. PER SQ. IN.

Sands Bonded with Bentonite

It was observed that the bentonite-bonded sands which were tested disintegrated on cooling from any temperature between 900°C. (1652°F.) and 1200°C. (2192°F.). Fig. 15 shows how a bentonite-bonded sand disintegrates on cooling from a temperature of 1200°C. (2192°F.).

If the bentonite-bonded sands were heated above 1200°C. (2192°F.), they did not disintegrate on cooling, but became very

strong. The bond of such specimens appeared glassy after cooling.

Fig. 16 shows a bentonite-bonded specimen which was heated at a rate of 3°C. (5.4°F.) per minute to 1540°C. (2804°F.) and then cooled to room temperature. The bond was fused, with the result that the sample deformed permanently under its own weight. Deformation did not occur until several minutes after the speci-
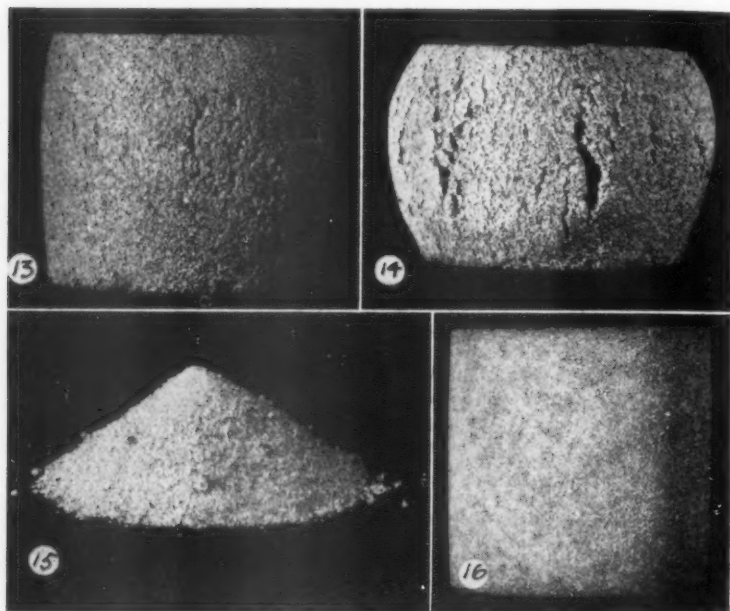
Fig. 13—A specimen of Portage No. 5 sand with 14 per cent fireclay after being heated to 1200°C. (2192°F.) at the rate of 3°C. (5.4°F.) per minute and held at 1200°C. (2192°F.) for 35 minutes. Mashing occurred at 280 lb. per sq. in. and the specimen failed in circumferential tension. The bond is partially fused, but does not have a glassy appearance.

Fig. 14—A specimen of Portage No. 5 sand with 14 per cent fireclay after being exposed to a temperature of 1300°C. (2372°F.) for 35 minutes. Mashing occurred at 83 lb. per sq. in., and the specimen failed in circumferential tension. The bond is fused and has a glassy appearance.

Fig. 15—The extent to which a Bentonite-bonded sand disintegrated upon cooling after being heated 10 minutes at 1200°C. (2192°F.). When loaded at 1200°C., the specimen mashed under a load of 16 lb. per sq. in. Specimen mixture: 50 parts. No. 30 +50 parts No. 424 washed sand, 6.25 per cent Bentonite, 4.2 per cent water.

Fig. 16—A specimen of No. 80 silica sand with 3.3 per cent Bentonite showing a slight deformation after being heated to 1540°C. (2804°F.) at the rate of 5°F. per minute. The bond was completely fused, and the specimen slumped under its own weight.

men had reached 1540°C. (2804°F.). On cooling, the specimen, instead of disintegrating, developed a strength of approximately 600 lb. per sq. in.

Sands Bonded with Fireclay

The sands bonded with fireclay did not disintegrate on cooling from any test temperature. When heated to temperatures between 900°C. (1652°F.) and 1200°C. (2192°F.), the specimens on cooling showed a decreasing strength with increasing test temperature. When heated to 1300°C. (2372°F.), the specimens on cooling were so fragile that it was difficult to handle them without breaking. If heated above 1300°C. (2372°F.), the strength after cooling increased with the temperature of heating. The specimen shown in Fig. 13 was heated to 1200°C. (2192°F.) and was stronger after cooling than the specimen which was heated to 1300°C. (2372°F.) (Fig. 14).

Sand Deformation

The total compression deformation of the sand specimens was measured at the maximum load for each temperature. Curves showing the relationship between temperature and deformation are given in Fig. 17.

All the sand mixtures tested behaved in a similar manner, in that the deformation increased very slowly up to the temperature at which the bond began to fuse. As fusing of the bond progressed, the deformation increased very rapidly.

Expansion-Contraction Tests

The results of expansion-contraction tests are not included in this report, for the reason that methods heretofore commonly used proved to be unsatisfactory at high temperatures. New apparatus has been constructed, and tests are now being made.

COMPARISON OF TESTS

If we look over the list of mixtures tested, it will be observed that four sands were used and that each was mixed with bentonite and with fireclay bond. It was directed that in each case the mixture be made up to show 7½ pounds green strength. In the following table (Table 2) these mixtures are arranged in pairs, and the heading of each column shows what it represents.
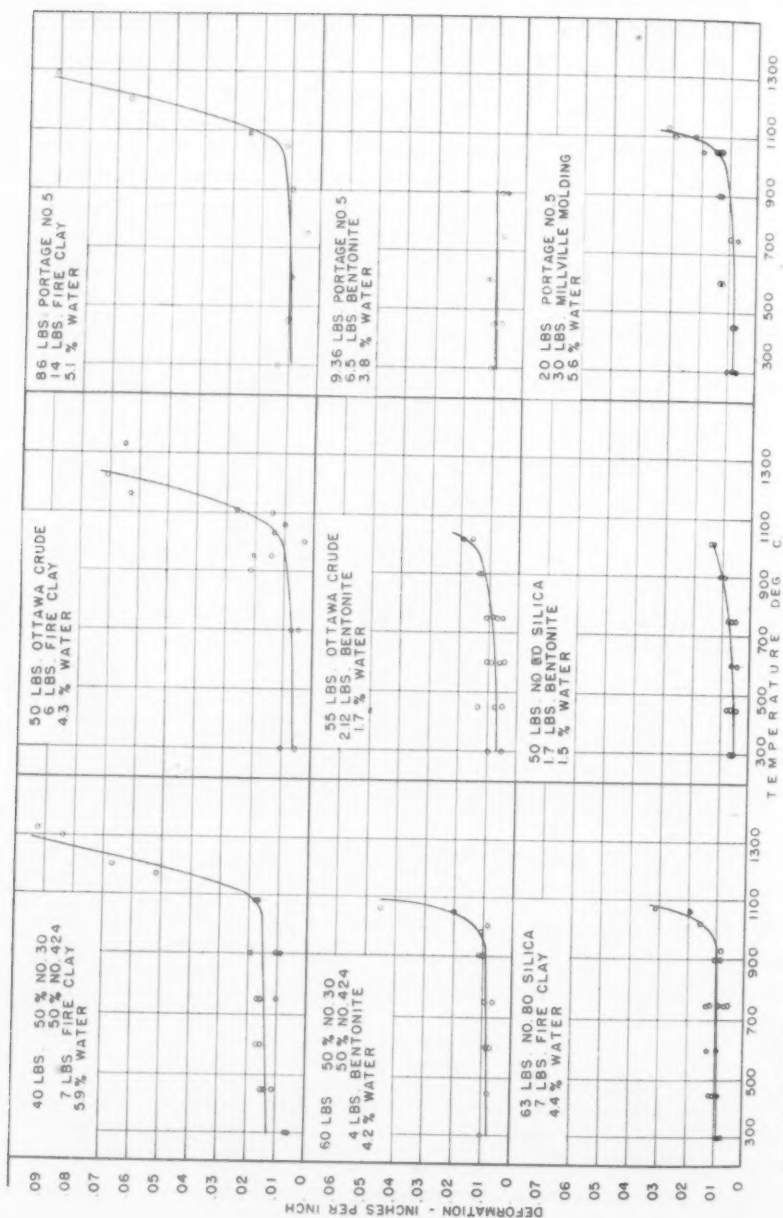
Fig. 17—Deformation curves. All mixtures when slowly heated deformed slightly under compression at different temperatures until the maximum strength was reached. Above this the deformation increased rapidly in the plastic zone.

Table 2

Fig. No.	Mix No.	Sand Used	Aver. Fineness	Per Cent Sand	Bond[1]	Per Cent Bond	Per Cent Water	Shock Limit °C.	Max. Str. lb.	Temp. °C.	Final Str. lb.	Temp. °C.	Dry Comp. Str. lb.
11	4B	No. 80	69.0	96.7	B	3.3	1.5	600	400	1000	25	1180	9
9	4C	No. 80	69.0	90.0	F.C.	10.0	4.4	600	600	1075	100	1300	33
10	1B	Ottawa Crude	38.1	96.3	B	3.7	1.7	750	300	1000	15	1200	10
8	1C	Ottawa Crude	38.1	89.3	F.C.	10.7	4.3	700	875	1110	60	1330	33
6	3B	30-424	42.13	93.75	B	6.25	4.21	600	1080	900	cracked		71
3	3C	30-424	42.13	85.1	F.C.	14.9	5.9	none	1300	1110*	70	1325	61
7	2B	Portage No. 5	41.0	93.6	B	6.4	3.8	450	1100	975	25	1220	100
2	2C	Portage No. 5	41.0	86.0	F.C.	14.0	5.1	none	1100	1075	80	1300	44

* Specimens Mashed.
[1] B=Bentonite. F. C.=Fire Clay.

Summary of Results and Conclusions

It is not safe to draw sweeping and definite conclusions from the tests thus far made, but it appears that the following can be drawn:

1. Neither the bentonite nor the fireclay-bonded sands as a group are unaffected by heat-shock.

2. Some sand mixtures were sensitive to heat-shock, and specimens made of these mixtures cracked at a comparatively low temperature. Other mixtures were unaffected by heat-shock and developed the same strength under shock-test conditions as they did when heated at a rate of 3°C. (5.4°F.) per minute.

3. The strength of the sand mixtures tested increased with temperature up to the temperature at which the bond began to fuse. At higher temperatures, the strength decreased rapidly and approached zero at the temperature of complete fusion of the bond.

4. The fireclay-bonded sands in every case reached their maximum strength on slow heating at a higher temperature than the corresponding bentonite-bonded sands. This difference averaged 75°C. (135°F.).

5. (a) The bentonite-bonded sands disintegrated on cooling from any temperature between 900°C. (1652°F.) and 1200°C. (2192°F.).

     (b) The sands bonded with fireclay became very fragile, but did not disintegrate on cooling from any test temperature.

     (c) Sand specimens bonded with either fireclay or bentonite developed a high strength on being cooled from the temperature at which the bond became completely fused.

6. The total deformation of the specimens at the maximum load did not increase appreciably with temperature until the bond began to fuse.

7. The composition of the mixtures did not permit the drawing of any conclusions regarding the effect of fineness of sand, amount of moisture, and amount of bond on the hot strength. Tests are now under way to obtain this information.

8. The hot strength at a given temperature in the plastic zone was always higher for the fireclay-bonded sands than for those bonded with bentonite.

The Influence of Undercooling on the Graphite Pattern of Gray Cast Iron

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Abstract

Gray irons of the same composition and method of manufacture may vary widely in their characteristics and these differences are not always capable of ready interpretation. Broadly, the physical properties of a cast iron are determined by two factors: (1) The nature of the matrix and (2) the amount, size, shape, and distribution of the graphite. Rate of cooling has a most important influence on these two factors.

With this in mind, the authors have worked with a wedge-shaped casting, placing thermocouples at six different places in the wedge mold. From the data obtained, cooling and hardness curves were drawn. Explanation of the results were made with the help of the cooling curves, hardness measurements, photomicrographs and magnetic transformation rate determinations. It was found that gray iron is quite susceptible to undercooling not only during solidification which influenced the graphite structure, but also during the austenite transformation which effect influenced the nature of the matrix.

Direct confirmation of these conclusions was attempted by taking molten iron in equilibrium at 2500°F. and instantaneously cooling or quenching small portions to some temperature below the theoretical eutectic freezing point, specifically in the range 1800°F. to 2060°F. The quenching was conducted by pouring 15 gram portions of molten iron into iron molds of relatively large mass and suitably preheated to the desired temperature. The thermal and micrographic results showed good correlation with the results in the wedge casting.

INTRODUCTION

1. It has long been observed that gray cast irons may vary widely in their physical properties and that these differences are not always capable of ready interpretation from a consideration of their composition or of the raw materials that were used in their manufacture. It is true, in general, that irons higher in carbon and silicon are weaker than those lower in these elements; and those made from certain pig irons may be stronger than those from other pig irons; the per cent of scrap and steel introduced in the charge can also influence the nature of the resultant castings. But, before an intelligent and quantitative evaluation can be arrived at regarding the influence of factors such as composition, raw materials, superheat, pouring temperatures, and ladle treatment, a better understanding must be had of the reasons why irons of the same composition and methods of manufacture can vary so widely in their characteristics.

CONTROLLING FACTORS OF GRAY IRON

2. It would seem from a logical approach to the problem, that the physical properties of gray cast irons must be controlled by two factors: (1) the nature of the matrix and (2) the amount, size, shape, and distribution of the graphite. Murphy[†] and Wood[1] have pointed out that irons having identical chemical analyses may possess different austenite transformation characteristics so that the nature and properties of the pearlite formed will therefore be different. In other words, castings of identical cross section and cooling rates but from different heats, may have matrixes varying from mixtures of ferrite and pearlite, coarsely lamellar pearlite, to a fine sorbite. Furthermore, a given iron poured into castings of different section size will likewise have a similar possible range of matrix structures.

Graphite Pattern

3. Frequently, properties such as transverse deflection, machinability, and wear resistance differ in irons of almost identical composition and these variations can be associated with the nature of the graphite pattern. Mahin and Hamilton[2] have proposed a classification for graphite patterns which have been found to occur in commercial and experimental irons. It is possible to obtain not only flake graphite with random orientation and of different lengths

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† Superior numbers refer to bibliography at end of paper.

but also graphite arranged in whorls, or in a dendritic, or in a eutectiform pattern. These different types of graphite will naturally influence the physical properties even if identical matrixes were present in each case.

4. Examinations of the microstructures in wedge castings by the authors have revealed that frequently all the graphite patterns of the Mahin and Hamilton classification may be found in the same piece of iron. At the point of these wedges the iron is white showing no graphite whatsoever; at various locations in the gray region, whorls, eutectiform and dendritic graphite can be seen; and at the heavy end long flakes are usual. Of course, these structures would be placed at different distances along the wedges of different irons, but in general, their relative positions to one another are the same.

RATE OF COOLING

5. This observation seems to indicate that the rate of cooling is responsible for differences in graphite pattern and that a certain amount of undercooling could be expected. Gray irons are quite sluggish materials upon freezing; that is, they do not freeze at the equilibrium eutectic temperature as given in iron-carbon-silicon constitutional diagrams except under very slow rates of cooling. Ruff[3] observed a ladleful of molten gray iron remaining liquid 35°F. below the theoretical freezing point for several minutes before it actually solidified.

Cooling Test

6. A test was made, therefore, to investigate the influence of the rate of cooling upon the microstructure. A heat of railroad scrap was melted down with some steel in a high-frequency induction furnace and was superheated at 2750°F. It was poured at 2550°F. into a wedge mold of green sand. The wedge was 12½ inches long, 2¼ inches high, and 2½ inches wide at the thick end as shown in Fig. 1. A low carbon and silicon iron was desired in order to insure a generous-sized white tip on the wedge. Six chromel-alumel thermocouples had been placed at intervals through to the center of the wedge; their locations are also given in the figure. These couples were made of 20-gage wire and were protected with porcelain tubes through the sand mold while the portions of the couples projecting into the molten iron were covered with a refractory mixture of 10 per cent bentonite and 90 per cent silica flour.
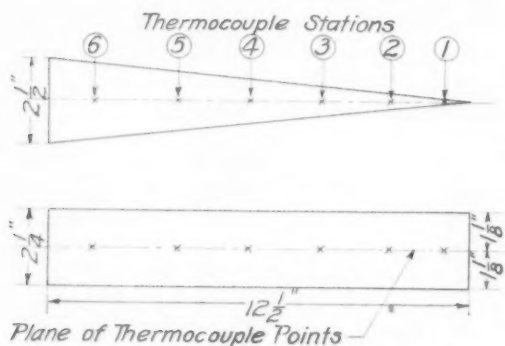
FIG. 1—SKETCH OF TEST WEDGE.
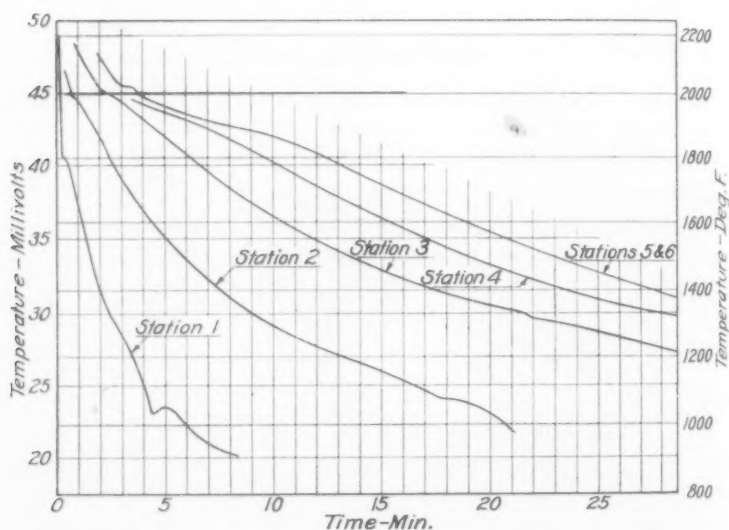
FIG. 2—COOLING CURVES AT THERMOCOUPLE STATIONS IN TEST WEDGE OF FIGURE 1.

Cooling Curves

7. Immediately upon pouring, temperature measurements were made simultaneously on six portable potentiometers in order that time-temperature cooling curves might be obtained down to 1000°F., well below the lower critical. The analysis of the iron showed 2.78 per cent of carbon and 1.50 per cent of silicon.

8. Fig. 2 shows the cooling curves taken at the six stations. Operators at two of the instruments were inexperienced and failed

to get their potentiometers under control until slightly below the freezing point. Inverse rate curves made for the other four stations show that with a rapid cooling rate there was considerable under-cooling; that is, the metal remained molten until a temperature well below the theoretical freezing point was reached. The actual solidification temperatures are given in Table 1 and in Fig. 3.

9. Similar behavior was observed in the austenite transforma-tion. Undercooling took place commensurate with the cooling rate so that the actual transformations occurred at temperatures below the theoretical A_1 point. The temperatures of transformation are also presented in Table 1 and in Fig. 3.

Table 1

SUMMARY OF TEMPERATURE DATA OBTAINED FROM WEDGE CASTING

Station Number	Thick-ness of Wedge, In.	Solidifi-cation Temp. °F.	Austenite Transfor-mation Temp. °F.	Nature of the Iron
1	0.19	1800	1050	White Iron—no graphite
2	0.50	1975	1075	Mottled Iron — eutecti-form graphite
3	0.875	1990	1300	Gray Iron — eutectiform graphite in dendritic dis-tribution
4	1.31	—	1300	About same as (3)
5	1.75	—	1290	Gray Iron—normal flake graphite
6	2.31	2030	1286	Gray Iron—normal flake graphite

HARDNESS CURVES

10. A study was then made on the wedge to follow the effect, if any, of undercooling upon the hardness and upon the graphite pattern. The wedge was sectioned, and hardness measurements were taken with both Rockwell and Brinell machines through the center along the full length of the piece. The results are shown graphically in Fig. 4.
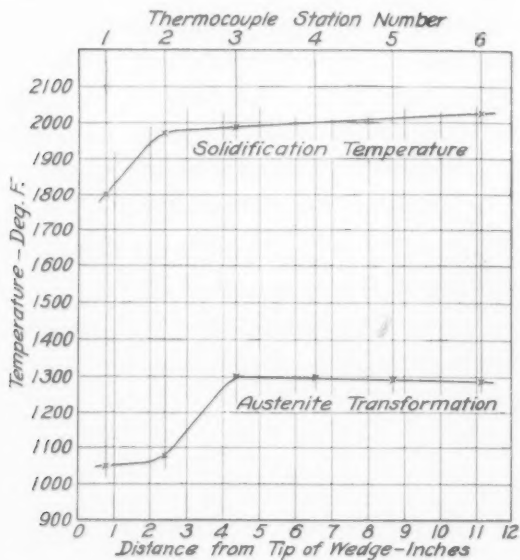
FIG. 3—SOLIDIFICATION AND TRANSFORMATION TEMPERATURES MEASURED ON THE WEDGE.
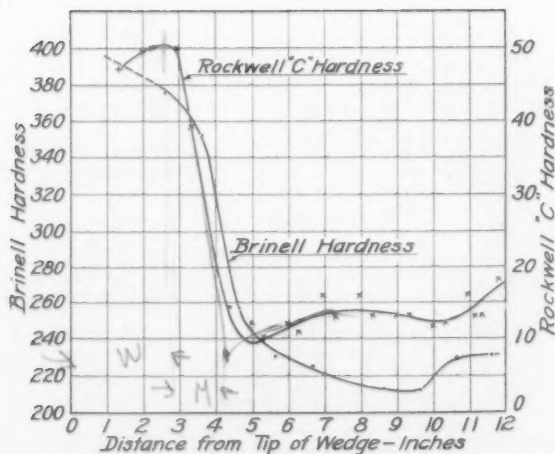
FIG. 4—HARDNESS CURVES FROM MEASUREMENTS ON WEDGE CASTINGS.
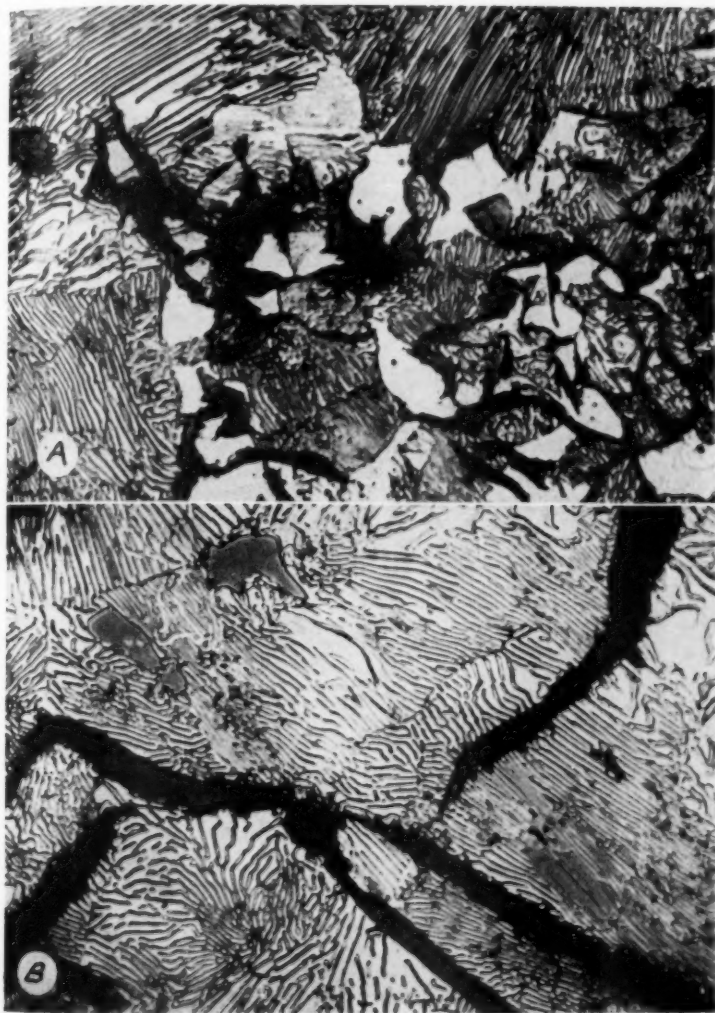
FIG. 5—A. REGION OF WEDGE CONTAINING FERRITE MATRIX. B. REGION OF WEDGE CONTAINING PEARLITIC MATRIX. BOTH MICROS AT 1000X.
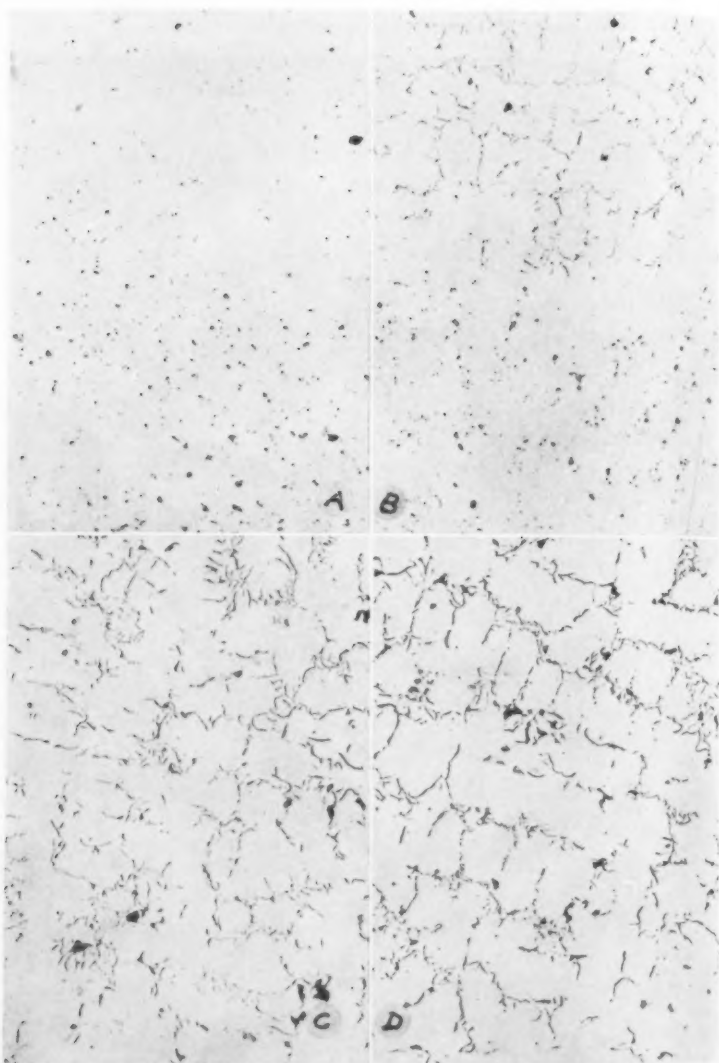
FIG. 6—UNETCHED CONDITION OF GRAPHITE PATTERN AT VARIOUS STATIONS. (100X) A. STATION 1. WHITE IRON— NO GRAPHITE. B. STATION 2. MOTTLED IRON—EUTECTIFORM GRAPHITE. C. STATION 3. GRAY IRON—EUTECTIFORM GRAPHITE IN DENDRITIC DISTRIBUTION. D. STATION 4. ABOUT SAME AS C.

Brinell Curve

11. The Brinell hardness curve shows that the hardness of the metal undergoes a great change as the location of the readings passed from the white zone through the mottle into the gray region. The hardness then diminishes very gradually to the hottest part of the casting about two inches from the heavy end where the metal is harder due to end-effect cooling.

Rockwell Curve

12. The Rockwell curve gives the same information except that a soft spot is indicated lying between the mottled and the gray zones. Since the Rockwell readings should be somewhat more sensitive, due to the smaller diameter of the penetrator, a metallographic examination was made to explain the cause of the soft area. Photomicrograph A of Fig. 5 at 1000 diameters shows that the matrix in this region contains ferrite whereas the region an inch farther from the tip has the pearlitic matrix shown in Photomicrograph B of Fig. 5.

Photomicrographs

13. Metallographic specimens were then cut in a manner such that a complete study could be made from the tip to the heavy end. Photomicrographs A, B, C, D of Fig. 6 and A, B of Fig. 7
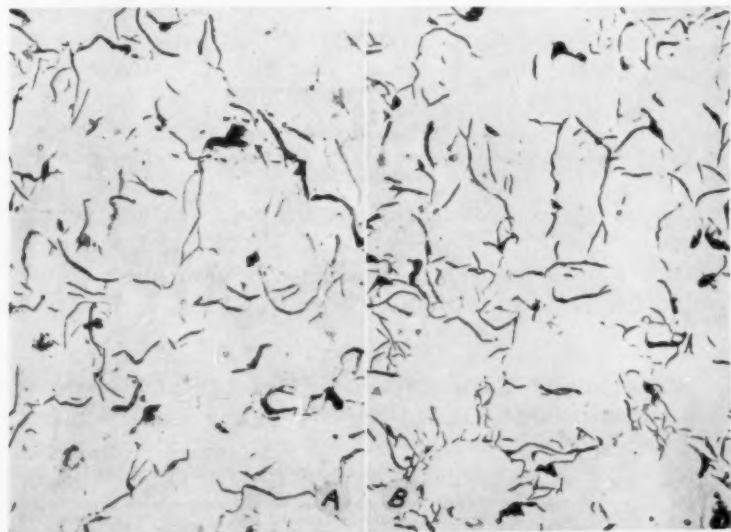
FIG. 7—UNETCHED CONDITION OF GRAPHITE PATTERN AT VARIOUS STATIONS (100X). A. STATION 5. GRAY IRON—NORMAL FLAKE GRAPHITE. B. STATION 6. ABOUT SAME AS A.

show in the unetched condition the graphite patterns at the six thermocouple stations. At station 1 the material was white iron and the freezing temperature was 1800°F. As the heavier end was approached the actual freezing temperature increased, approaching the theoretical, and the graphite pattern passed through the stages of eutectiform, dendritic, and normal flake types. Table 1 summarizes this information. In many respects these data are in full accord with the observations of Bolton and of others.

14.   From these data it can be seen that the rate of cooling markedly influences the graphite pattern. A study was made, then, to determine its effect on the matrix properties. Specimens were cut 3¾, 6¼, and 11 inches respectively from the tip of the wedge. The lower critical temperature for each of these samples was run and proved to be 1342°F. in each case.
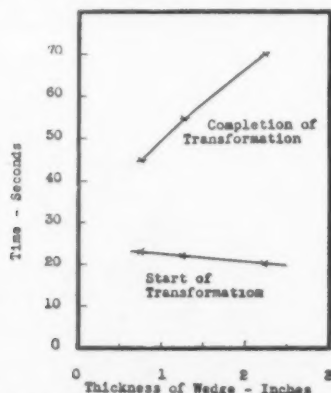
FIG. 8—INFLUENCE OF SECTION SIZE OR RATE OF COOLING ON THE RATE OF AUSTENITE TRANSFORMATION.

15.   New specimens taken from the same locations were then heated to 1700°F. and quenched at 1100°F. and the rate of austenite transformation was determined by magnetic means. The results of these tests are given in Table 2 and Fig. 8. It is evident

Table 2

INFLUENCE OF RATE OF COOLING DURING SOLIDIFICATION
ON CRITICAL POINTS AND AUSTENITE TRANSFORMATION RATES

Distance from Tip of Wedge in In.	Approx. Thickness of Wedge in In.	Critical Point °F	Time Required to Start Transformation Seconds, 1100°F.	Time Required to Complete Transformation Seconds, 1100°F.	Time Between Start and Completion of Transformation Seconds, 1100°F
3.75	0.75	1342	23	45	22
6.25	1.25	1342	22	55	33
11.00	2.187	1342	20	70	50

that the cooling rate during solidification of a gray iron not only affects the nature of the graphite pattern but also its austenite transformation rate and hence the properties of the matrix.

16. As long ago as 1929, Norbury[5] came to the conclusion that finely divided graphite is associated with supercooling and flake graphite, with "normal" solidification from observations of data similar to those described in this paper. It was felt, however, that more direct evidence is desirable and a series of tests was conducted to this end.

17. Certain assumptions were made in outlining these tests. First, it was assumed that solidification of iron-carbon-silicon alloys of eutectic composition may take place with the formation of an austenite-carbide eutectic under some conditions and an austenite-graphite eutectic under others. Boyles[6] has demonstrated the direct precipitation of graphite from the melt without the necessity of conceiving an intermediate carbide step. This view is strengthened by the data of Schwartz[7] and of Wells[8] who showed that pure Fe_3C is unstable at the melting point. An iron carbide containing silicon is even less stable.

18. Secondly, the solidification of the liquid of eutectic composition was viewed in the light of a chemical reaction or a transformation. In fact, a very close parallel may be drawn between the liquid-to-solid transformation and the austenite-to-pearlite transformation. In each case the reaction will occur at a definite temperature under very slow rates of cooling and at a lower temperature under faster rates of cooling (super-cooling). Heat is evolved by both transformations. If the cooling rate is extremely great, normal transformation will not take place at all. In the case of cast iron solidifying ledeburite, a metastable phase, is obtained rather than graphite; in the case of austenite transformation, a martensite is produced which is metastable when compared to pearlite.

Austenite to Pearlite Transformation

19. The third assumption was that a modification of Bain's method is studying the austenite-to-pearlite transformation at various constant temperatures could be worked out for solidification of cast iron. The results might produce direct evidence on the influence of the temperature of actual solidification of the eutectic liquid upon the graphite pattern.

20. A short description of the fundamental points in Bain's[6] work is given here in order to bring out the parallel of the proposed investigation with his experiments. Bain heated thin steel specimens at some temperature above the critical until they were completely austenitic and then plunged them into a bath of molten lead at some temperature below the critical. After holding at this second temperature for varying lengths of time, the specimens were removed and quenched into water. Metallographic examination of a series of specimens which had been heated at 1550°F., for example, and then cooled to 1200°F., showed that the austenite was capable of undercooling; that is, the austenite failed to transform at the normal transformation temperature of 1300°F. Instead it transformed to pearlite at 1200°F. and only after some definite period of time had elapsed. The reaction commenced at pearlite nuclei which formed and pearlite crystals then grew at the expense of the austenite until the transformation was complete.

21. By changing the temperature of the lead bath, the time to initiate the process and also the time to complete it was found to vary. The nature of the final transformed product proved to be characteristic of the temperature at which the transformation was permitted to occur. For example, a lead bath temperature of 1250°F. produced coarsely lamellar pearlite; a temperature of 1150°F., a finer pearlite; temperatures between 500°F. and 900°F. a martensite-like structure called Bainite. Transformation temperatures below 400°F. produced true martensite.

Undercooling of Cast Iron

22. To use a similar method of study, a means would have to be developed by which molten cast iron at equilibrium at, say, 2500°F. could be instantaneously cooled to some temperature as 1900°F. by pouring into a suitable medium. The information gained from the data from the wedge experiment showed conclusively that cast iron is susceptible to undercooling. The molten iron would, therefore, be cooled very rapidly to 1900°F., remain liquid at that temperature momentarily at least, and would finally solidify with a grain structure and graphite pattern. The behavior at other quenching temperatures should be similar but solidification should take place with different grain structures and graphite patterns in accordance with Tamman's[10] findings on the rate of crystal and nucleus formation.

Crystal Growth

23. Tamman showed that when a melt solidified, the rate of crystal growth and the number of crystal nuclei were influenced by the degree of undercooling. In other words, if the temperature of solidification were very slightly below the theoretical, the rate of crystal growth is slow and the time necessary for solidification is great. The number of nuclei of crystal centers is small so that few though large crystals result. As the degree of undercooling is increased, the actual solidification temperature is lowered, the rate of crystal growth and the number of nuclei both increase. This means that undercooling promotes finer grain. As the degree of undercooling is still further increased, the rate of crystal growth gradually becomes less due to increasing viscosity of the liquid so that solidification is accomplished by the formation of many crystal centers none of which can grow very much. This results in an exceedingly fine grain such as seen in a chilled edge.

24. A study was made in order to investigate whether the mechanism of solidification normal to all pure metals and pure compounds would apply to some extent, at least, to the freezing of gray cast iron. It seemed possible that a parallel behavior might be encountered between the number and size of crystals in the solidification of pure metals in relation with the degree of undercooling as observed by Tamman and the number and resultant size of graphite flakes in the solidification of gray cast iron.

Experimental Data

25. Heats of iron, 300 grams in weight, of a mix identical to that of the wedge were melted in the high frequency induction furnace. The superheating temperature was 2750°F. and the pouring temperature 2500°F. A 10-15 gram portion was cast into a split steel mold shown in Fig. 9. This mold was placed in a gas-fired crucible furnace and its temperature adjusted manually by means of a thermocouple placed 3/32 inch from the inner mold surface. The relatively large mass of the mold as compared with the 10-15 grams of molten iron poured therein and its high thermal conductivity were sufficient to cause almost instantaneous chilling of the melt to the mold temperature. For all practical purposes, therefore, the temperature of solidification of the metal may be assumed to be equal to that of the mold. The mold was kept at this temperature for a period of four minutes after the metal was poured; it was then removed from the furnace and cooled to room temperature. The couple was not placed in the melt because of
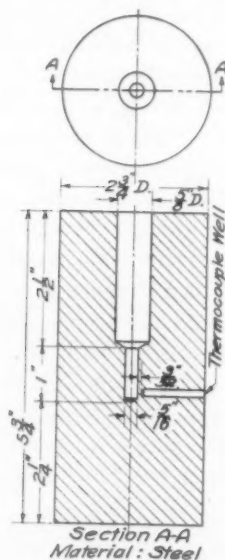
FIG. 9—SKETCH OF STEEL MOLD USED FOR LOWERING IRON TEMPERATURE.

danger of alloying and possible interference with the normal solidification structures due to alloying.

Test Temperatures

26. A series of runs was made with different mold temperatures, varying from 1818°F. to 2070°F. The specimens as cast were then removed, cut, and polished for metallographic examination in the unetched condition. Photomicrographs A, B, C, D of Fig. 10 and A, B, C of Fig. 11 and Table 3 summarize the results. The thermocouple indicated, in each heat, a rise of about 5°F. shortly after the molten iron was poured into the mold. The temperature then dropped to the starting temperature within a minute.

27. Heat 10A was held at 2070°F. which is evidently in the region where austenite and the melt are in equilibrium. After being held four minutes at this temperature, the remaining liquid was cooled at an indeterminate rate in a manner such that solidification took place to produce carbides. These carbides broke down to form the temper carbon particles visible in Photomicrograph A of Fig. 10. Upon consideration of Heats 10A and 12A, it would seem that the equilibrium eutectic solidification temperature for this iron must lie between 2070° and 2060°F.
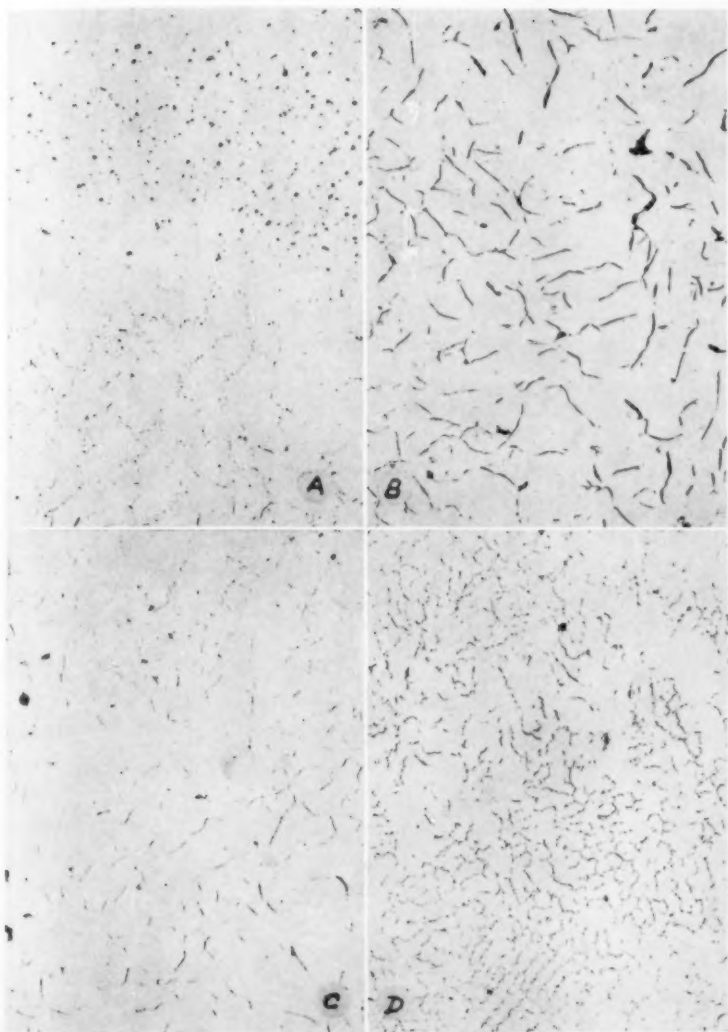
Fig. 10—Unetched micrographs (100x). A. Mottled Iron. Carbide plus Nests of Eutectiform Graphite. B. Gray Iron. Normal Flake Graphite. C. Gray Iron. Normal Flake Graphite. D. Gray Iron. Some Short Flake Graphite. Some Eutectiform Graphite in Dentritic Dispersion.
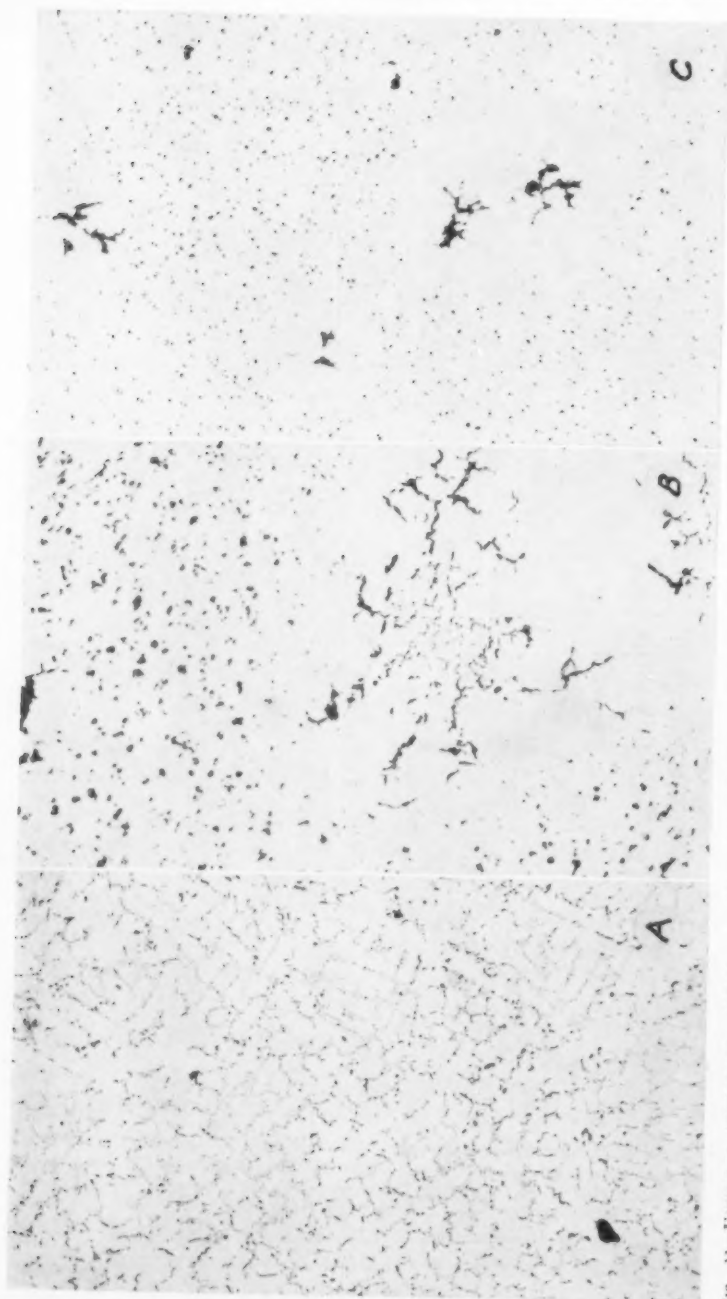
FIG. 11—UNETCHED MICROGRAPHS (100x). A. GRAY IRON. EUTECTIFORM GRAPHITE IN VERY DENDRITIC DISPERSION. B. MOTTLED IRON. CARBIDE PLUS EUTECTIFORM GRAPHITE. C. WHITE IRON. TRACES OF GRAPHITE AND SOME TEMPER CARBON FORMED DURING COOLING.

Table 3

INFLUENCE OF TEMPERATURE OF SOLIDIFICATION
UPON THE GRAPHITE PATTERN IN A GRAY IRON

Heat Number	Mold Temp. °F.	Type of Graphite
10A	2070	Mottled Iron. Carbides plus nests of eutectiform graphite.
12A	2060	Gray iron. Normal flake graphite
9A	2040	Gray iron. Normal flake graphite.
7A	1992	Gray iron. Same short flake graphite. Some eutectiform graphite in dendritic dispersion.
8A	1970	Gray iron. Eutectiform graphite in very dendritic dispersion.
13A	1955	Mottled iron. Carbides plus eutectiform graphite.
6A	1818	White iron. Traces of graphite and some temper carbon formed during cooling.

28. As the mold temperature was lowered, or in other words, as the temperature of solidification was lowered to just below the equilibrium freezing point, the resulting graphite is of the normal flake type. A greater degree of undercooling brings about a greater tendency for diminishing the length of the flakes and for the formation of a dendritic pattern. At 1970°F. almost 100°F. below the equilibrium temperature all the graphite formed is truly eutectiform.

29. When the liquid-to-solid transformation temperature is lowered still farther, the formation of the austenite-graphite eutectic is inhibited and an austenite-carbide eutectic is produced instead. In this case, white iron results. The small spots of temper carbon observed in Heat 6A were formed from the carbide during the time the metal was held at and cooled from 1818°F. to room temperature.

CONCLUSIONS

30. If the results of the wedge-casting study in Table 1 and of these quench tests in Table 3 are compared, it can be seen that there is fair agreement with respect to the type of graphite formed with different degrees of undercooling.

31. There are many limitations to this type of test which was conducted as a preliminary step in a broader program and the results are far from complete. First, time-temperature rela-

tionships of the solidification process could not be measured without an especially adapted oscillograph. Secondly, freezing is not a simple process of eutectic solidification due to the fact that the commercial cast irons are not completely eutectic. Crystallization is complicated by the presence of some primary austenite. It is logical to believe that the per cent of primary austenite present in an iron of given composition will vary depending upon the amount of undercooling. Thirdly, the temperatures measured in the quench tests were those of the mold surface rather than that of the melt itself. The good agreement in results of the quench tests with those of the wedge where actual iron temperatures were measured would indicate that this error is of no great amount.

32.   In spite of these limitations, however, some broad conclusions may be drawn:

(1) Cast iron is susceptible to undercooling.

(2) For the composition studied, undercooling may be as great as 100°F. below the theoretical equilibrium freezing point and still produce gray iron.

(3) Solidification temperatures between 2060°F. and 1970°F. produce graphite patterns which are characteristic of the actual freezing temperature. The lower the temperature, the finer will be the graphite and the greater the tendency for a eutectiform pattern.

(4) Still greater degrees of undercooling will inhibit the precipitation of graphite to form mottled and white irons.

(5) Undercooling increases the resultant austenite transformation rates.

33.   It can be seen, therefore, that the liquid-to-solid transformation has qualitatively, at least, many points in common with the austenite-to-pearlite transformation. Different steels will respond differently to the same cooling or quenching rate due primarily to their individual transformation characteristics; an air cooling from 1600°F. may render a plain carbon steel soft and a nickel-chromium steel hard for this reason. Different cast irons should likewise have different undercooling characteristics. Further research is being conducted to show whether or not irons of varying compositions will have undercooling ranges different from the one reported in this paper. The raw materials used, the ladle treatment, and the method of melting should also affect the behavior or response of an iron to a given amount of undercooling. When the influence

of these factors is fully understood, it may then be possible to explain many of the apparently contradictory results obtained in the foundry and a step will have been made toward controlling the graphite pattern in gray cast iron.

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DISCUSSION

Presiding: Dr. James T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

M. G. Corson[1] *(Written discussion):* The authors do not offer any data on the amounts of combined and graphitic carbon present. The hardness variations recorded might be due in the same measure to the change of the ratio graphite to carbide as to the rate of dissociation of austenite. I feel, however, that they cannot be seriously blamed for this omission, as the cost of the analytical work may have been prohibitive.

On the other hand, I feel that too much attention is paid to the "shape of graphite." There is much talk about "rosettes," "dendrites" and "eutectiform" graphite, but do these shapes have a real meaning? What does a "shape" represent? Merely a certain combination of the flakes of graphite that strikes our imagination. Between a single flake and a dendrite there are many intermediate shapes which we pass without noticing. The shape might mean something if we would study statistically the occurrence of different shapes through a section and from one section to another.

The important thing is not the shape of the agglomerate, but the size of the individual flake and its orientation in a given section. Just imagine a section of a test bar filled with flatly arranged flakes of graphite. What will be its strength? Very close to zero.

Now, I spent a great deal of time computing the possible arrangements of the flakes in an ordinary test bar. I estimated that should one try to cast a bar 1-in. thick and ½ mile long, there might happen a section exactly so arranged. The chance is one in ten million, i.e., such a section might occupy a length of 0.1-in. in the whole length of the bar.

This example shows that encountering a section of this kind is next to impossible. On the other hand there may be various arrangements of a certain number of flakes lying flat while a certain number of others are hitting the cross section almost perpendicularly, an arrangement which can actually be encountered in the usual 1-in. long test bar (about one chance in 250), there may be arrangements occurring once in 2000 sections and therefore defining the strength of an 8-in. bar, etc.

I developed a number of graphs showing the chances of a certain combination of flakes occurring in a sample whose total amount of graphite and size of the flakes (average values for length and thickness) are known. They convince me that the possible combinations of flakes whether they look like "dendrites," "randoms," "eutectiform," etc., can be accounted for and that the distribution of such combinations accounts for the strength of cast iron.

I believe that the time is ripe to stop merely taking nice pictures and to begin to evaluate them mathematically. For the foundryman and

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[1] Metallurgical Consultant. New York City.

the user of the castings cannot be satisfied with pictures no matter how dainty. They want to know the characteristics to which a picture may correspond. They need reliable predictions.

This country was remarkably successful in developing ways and methods for properly polishing gray irons. I believe that today at least ten laboratories in this country can produce photomicrographs where graphite looks like graphite and not like a dark and deep crack. I am sure that no one on the continent of Europe manages to get such excellent photographs.

But why limit ourselves to a purely mechanical task of artistically polishing samples of gray iron? Why not pass on to the mathematical exploration of the subject in question?

J. S. VANICK[2]: Dr. Schneidewind has made clear that these structures vary with composition which, I believe, is an extremely important feature to those who have to study them. Then, of course, the treatment of an iron, or rather the relation between these structures and the condition of casting is bound to differ quite a bit, because very few castings are subjected to the intense cooling rate that may be represented in the tip of these wedges. In this connection, I am thinking of broad wearing surfaces such as cylinder liners and surfaces of that type, rather than edges or sharp fins. So that foundrymen in general have a measure of security in the natural relationship of a surface to the casting and can make adjustments, both in their base metal mixtures and in their treatments of these irons to avoid a great deal of what seems to be a risk in producing a structure of this kind.

CHAIRMAN MACKENZIE: I would like to question the accuracy of that thermocouple reading in the tip of that wedge. I can hardly conceive of a thermocouple acting fast enough to come up to temperature right in the tip. It looks to me as though you might have some error there.

DR. SCHNEIDEWIND: As for the temperature measurements in the tip, we had our best graduate student, with our best potentiometer, who caught the temperature when it was passing 2200°F. and was on the way down. All this occurred in a matter of something like 15 to 20 sec. Readings were taken every five sec.; one man called time from a stop watch, one man was reading at each of the six potentiometers and one man recorded the data at each potentiometer. In all thirteen men were used to obtain data. The readings at the tip of the wedge were obtained very satisfactorily.

These low solidification temperatures are not anything new. Bolton reports similar data on p. 222 of his text book "Gray Cast Iron." The bars varying from ½ to 4 in. in diameter.

With regard to the discussion by Mr. Corson, that ferrite right behind the mottled zone, I doubt whether that is due to the transforma-

tion rate. This, however, brings up a very controversial point as to how so-called primary ferrite is formed. Bancroft and Dierker* wrote a paper on that subject about two years ago.

With regard to the photomicrographs and the amount of graphite present, it is true that our polishing methods are imperfect, but Mr. Crosby and Mr. Timmons, of the Climax Molybdenum Company, claim that by using the lead-lap process of polishing, where a polishing disc is covered with lead and impregnated with powder, they have been able to take photomicrographs and estimate the density of the iron from the photomicrograph very closely, whereas if they polished by the regular methods, they obtained density errors that were quite large.

I would like to point out that this eutectiform pattern is not rare. We can produce it every time if desired. The composition, rate of cooling and furnace treatment all contribute to its production.

Mr. Vanick felt that a cylinder liner would not be subjected to fast rates of cooling. That, however, depends upon the size of the cylinder liner. We have made some liners, at a foundry with which I was associated, that had a minimum section of a little under ½-in. Of course, it would not cool as rapidly as the tip of a wedge because there is some mass effect, but the cooling rate should be comparable. Since the paper was written we have worked with other compositions and find that the temperature ranges for producing various graphite structures vary with composition.

MEMBER: What type of thermocouple was used in measuring the temperatures? While I do not know, I believe they were protected too much, giving a thermal lag which might have had some effect.

DR. SCHNEIDEWIND: That is quite true. There might have been a thermal lag. These were chromel-alumel couples placed in the mold; the tip was covered with a wash of 10 per cent bentonite and 90 per cent silica sand. There was a protection tube all the way up to the metal but in the metal itself the tip was protected only with a thin layer of bentonite and sand. I know that a chromel-alumel couple is not accurate within about 10°F., but we did get comparative readings.

MEMBER: Would Dr. Schneidewind discuss a little more his theory concerning that primary ferrite just back of the tip of the wedge?

DR. SCHNEIDEWIND: I would be guessing just like everybody else does on that subject. I believe that as cast iron freezes, the austenite solidifies first leaving molten eutectic liquid. The eutectic may then freeze in one of two forms. It may freeze either as a cementite-austenite eutectic or it may freeze as a graphite-austenite eutectic. Honda believed that cementite must form first, which immediately breaks down to form graphite. I think, however, the work of Boyles shows that Honda's belief is not true, and, thermodynamically, there does not seem to be any

* Trans. A.F.A. Dec. 1937—"Ferrite—Its Occurrence and Control in Gray Cast Iron" pp. 449-466.

justification for Honda's theory, because more heat is given off by the graphite system than by the cementite system. When undercooling is severe, this eutectic liquid may solidify as graphite and austenite but the austenite may not have had opportunity to become saturated. When this low-carbon austenite later transforms, it can result in pearlite and some ferrite because there was insufficient carbon in the austenite to form a completely pearlitic matrix.

Rapid Temperature Measurements of Cast Iron With an Immersion Thermocouple

By FULTON HOLTBY,* MINNEAPOLIS, MINN.

Abstract

The author reports on the investigation of rapid temperature measurements of cast iron using an immersion thermocouple. Optical pyrometers, platinum — platinum — 10 per cent rhodium thermocouple, tungsten — graphite couples and other forms of temperature measuring devices are experimented with. The results obtained from the use of the tungsten — graphite immersion type thermocouple proved very satisfactory. Some of the advantages were temperature measurements unaffected by the presence of smoke or slag. Temperature measurements can be made in small ladles rapidly. The size of the tungsten-graphite couple can be made smaller than that of other high temperature couples. Photographs and data of the various couples used in this experiment are included.

INTRODUCTION

1. Three research investigations now being carried on at the University of Minnesota foundry laboratory require a large number of quick, accurate, and relatively high temperature measurements. This paper will discuss the difficulties encountered and the method which was developed to obtain accurate results.

TEMPERATURE REQUIREMENTS

2. The temperature measuring device used in these investigations had to satisfy the following requirements:

(a) Rapid, accurate measurements of cast iron up to 3000°F. in an electric furnace.

(b) Rapid, accurate measurements of cast iron at 2600°F. in a small 30-lb. hand ladle.

3. A Leeds and Northrup optical pyrometer, a platinum-platinum-10 per cent-rhodium thermocouple, and a Leeds and Northrup manually-operated, portable-type, potentiometer were available when these investigations were started.

OPTICAL PYROMETER

4. The optical pyrometer determines the temperature of a hot body by measuring the intensity of the radiation for a single wave length given off from the body. Any absorbing medium, such as fumes or smoke, reduces the intensity of the radiations to the pyrometer. Likewise, any contaminating substance, such as slag on the surface of the metal, or any radiations from other sources reflected from metal to the pyrometer, will give serious errors in temperature measurements.

5. Materials added to molten cast iron, used in our investigation, caused excessive fumes and slag in the furnace and ladle. Preliminary temperature readings with the optical pyrometer, under these conditions, gave variable readings of 250 to 350°F. lower than the temperature as shown by a calibrated platinum-platinum-10 per cent-rhodium thermocouple.

6. These differences between apparent temperatures, as observed by an optical pyrometer, and the true temperatures, as obtained by the platinum-platinum-10 per cent-rhodium thermocouple, were investigated by Wensel and Roeser.[1] They found that the uncorrected optical pyrometer readings were about 100°F. low for molten iron below 2500°F., about 230°F. low for iron at 2552°F., and about 284°F low at 2900°F. Obviously, the optical pyrometer could not be used under these conditions.

OPTICAL PYROMETER READINGS UNDER BLACK-BODY CONDITIONS

7. An attempt was made to eliminate the effect of the absorbing media, such as fumes and smoke, and the variable emissivity due to the changes in slag and reflected radiation on the surface of the metal. The optical pyrometer was equipped with a closed tube, the end of which was a thin shell of graphite. The construction of this tube is shown in Fig. 1. This closed graphite tube was immersed in the iron and the optical pyrometer observations were obtained by sighting on it. These observations under black-body

† Superior numbers refer to bibliography at end of this paper.

conditions eliminated errors due to smoke in the furnace or over the ladle, and the emissivity corrections.

8. However, when the readings from this pyrometer were checked with a platinum-platinum-10 per cent-rhodium thermocouple held against the graphite shell in metal, they were found to be as much as 70°F. too low. This error in reading was found to be caused by vapors coming from the graphite shell. To eliminate these vapors or fumes, the black-body tube was heated for several hours at 2000°F. The readings then, when taken in molten iron, were only 10°F. lower than those read by the platinum couple. This checked closely with the results obtained by T. L. Joseph[2] in using an optical pyrometer with a black-body tube to measure the temperature of pig iron in a blast furnace runner.
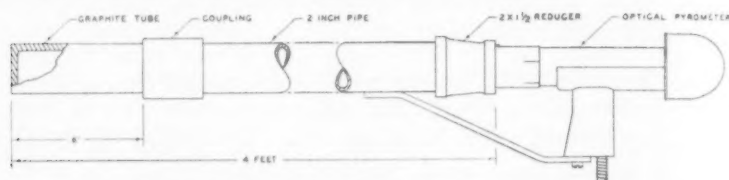
FIG. 1—BLACK BODY TUBE USED WITH OPTICAL PYROMETER.

9. While this method of temperature measurement gave fairly accurate results and can be used to check emissivity values quickly, the apparatus was too unstable to give continuously accurate results. The closed graphite shells did not last long after they had been subjected to enough heat to stop them from smoking.

PLATINUM-PLATINUM-10 PER CENT-RHODIUM THERMOCOUPLE

10. A platinum thermocouple, when used to measure temperatures of molten cast iron, must have two protecting tubes. The inner tube must be gas tight to protect the platinum wires from carburizing gases. The outer tube must protect the inner tube from rapid thermal shock and from errosive slag or gases. At present, no single tube is marketed for molten cast iron which will take the place of these two tubes. A platinum thermocouple is limited to a maximum safe temperature reading of about 2900°F.

11. The couples used for our investigation were 30-in. long and made of a 22-gauge pure platinum wire, welded to a 22-gauge alloy wire of platinum-10 per cent-rhodium. This thermocouple is known as the Le Chatelier or noble metal couple. The inner protecting tubes were sillimanite (porcelain) and the outer protecting tubes were graphite.

TYPE A   TYPE B   TYPE C.
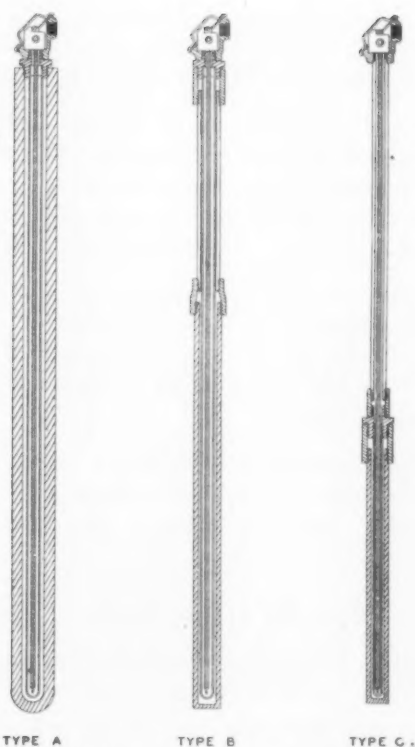
FIG. 2—PROTECTION TUBES FOR PLATINUM-PLATINUM 10 PER CENT RHODIUM THERMOCOUPLES.

12. A Leeds and Northrup potentiometer was used to measure the thermal e.m.f. from the couple. Compensating extension lead wires were used to extend the cold junction to the potentiometer.

PROTECTING TUBES FOR NOBLE METAL COUPLE

13. Three combinations of protecting tubes were tried. The assembly of these tubes is shown in Fig. 2.

14. Type *A* had an inner protecting tube of sillimanite 11/16-in. O.D. (outside diameter) and 7/16-in. I.D. (inside diameter). The outer protecting tube was graphite, 2-in. O.D. and 1-in. I.D.

15. Type *B* had an inner protecting tube of sillimanite 11/16-in. O.D. and 7/16-in. I.D. The outer protecting tube was graphite, 1¼-in. O.D. and ⅞-in. I.D.

16. Type C had an inner protecting tube of sillimanite 23/64-in. O.D. and 15/64-in. I.D. The outer protecting tube was graphite, 1-in. O.D. and 5/8-in. I.D.

17. Type A required over 4 min. of immersion time to obtain a reading, starting from room temperature. The heat capacity of the protecting tube was so great that the metal in the 30-lb. ladle would fall below the required pouring temperature before a reading could be obtained.

18. Type B, with the thinner graphite protecting tube, would give a reading, starting from room temperature, in about 2 min. The graphite tube did not give ample protection to the sillimanite and if the unit was not heated slowly before immersion, the sillimanite tube would break.

19. Type C had a smaller sillimanite tube and readings could be obtained in $1\frac{1}{2}$ min. from room temperature. These tubes, however, would crack if handled roughly or immersed too rapidly in iron at 2800°F.

CONSIDERATION OF OTHER PYROMETERS

20. The errors in the optical pyrometer readings due to smoke and slag conditions, the size and shortness of useful life of the black-body tube with an optical pyrometer, and the temperature limitations and thermal lag of the protected noble-metal couple, made it necessary to consider some other type of temperature measuring device.

21. Various thermocouples, using refractories or high melting point metals as the elements, have been discovered and developed within the past few years. The most notable of these are: The carbon-graphite couple[3]; the tungsten-molybdenum couple[4]; the tungsten-graphite couple[5]; and the silicon carbide-graphite couple[6]. These various couples were considered as possible temperature measuring devices for our investigation.

22. The carbon-graphite couple[3], while simple in construction, has the possibility of conversion of carbon to graphite at high temperatures and hence a change in calibration. The millivolt output is also very small as compared to a platinum couple.

23. The tungsten-molybdenum couple[4] is easily attacked by oxidizing atmospheres, has a reversible polarity, and gives low thermal e.m.f. readings as compared to a noble-metal couple.

24.   The tungsten-graphite couple, as described by Watson and Abrams[5], was too large and had too much heat capacity for ladle immersion use. However, its characteristics and properties seemed ideal for our work.

25.   The silicon carbide-graphite couple[6] was also too large and expensive to buy or make. The electromotive force given by this couple, namely about 500 millivolts at 3000°F., was beyond the limit of our potentiometers.

THE REVISED FORM OF THE TUNGSTEN-GRAPHITE COUPLE

26.   At the suggestion of C. E. Wood, supervising engineer, Northcentral Experiment Station, United States Bureau of Mines, a form of the tungsten-graphite couple, as revised by him, was considered. This couple had been used by W. F. Holbrook[7] in connection with investigations at the Northcentral Experiment Station.

27.   Four tungsten-graphite couples were built and used for temperature measurements in the electric furnace and in the ladle. An assembled and unassembled couple is shown in Fig. 3.

28.   The elements of the tungsten-graphite couple, as used in our work, consisted of a 1/10 in. diameter tungsten rod 30 in. long and a graphite tube.

29.   The graphite tube was made from a 3/4-in. diameter graphite electrode. A 1/4-in. hole was drilled lengthwise through the center and one end tapped with a $\frac{5}{16}$-24-N.F. thread. The other end was threaded on the outer diameter with a 3/4-10-N.C. thread. Since these electrodes were purchased in 24-in. lengths, a graphite threaded sleeve, or coupling, and a 6-in. threaded graphite nipple were used to make 30-in. of graphite tube.
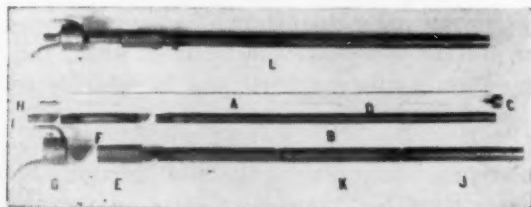
FIG. 3—IMMERSION TYPE TUNGSTEN-GRAPHITE THERMOCOUPLES. (A) TUNGSTEN ROD. (B) GRAPHITE TUBE. (C) GRAPHITE PLUG. (D) PORCELAIN INSULATOR. (E) GRAPHITE COUPLING. (F) GRAPHITE NIPPLE. (G) BRASS WATER COOLED HEAD. (H) BRASS TERMINAL COUPLING. (I) BAKELITE CAP. (J) LOWER GRAPHITE TUBE. (K) UPPER GRAPHITE TUBE. (L) ASSEMBLED THERMOCOUPLE.
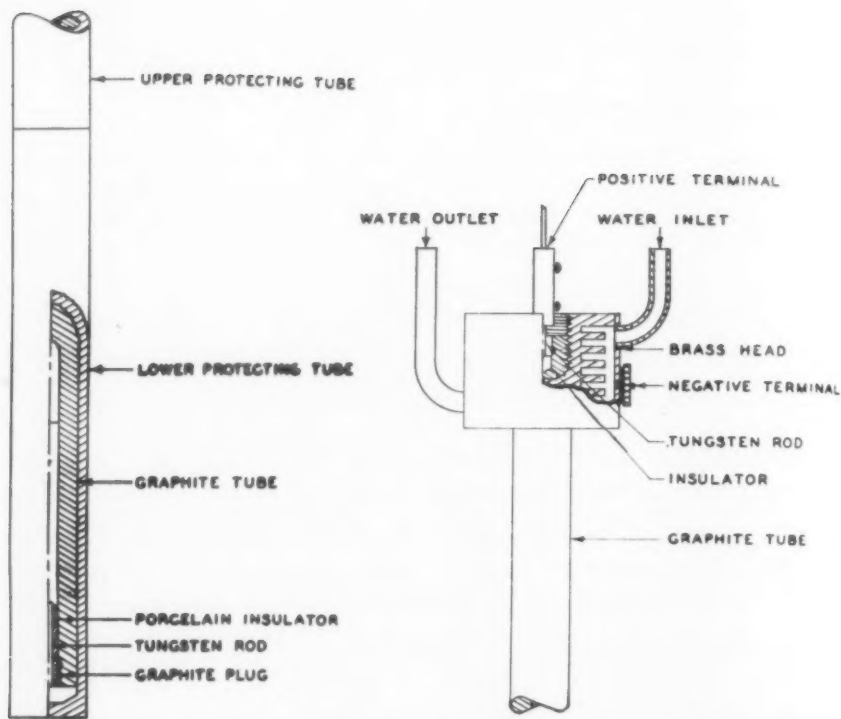
Fig. 4 (Left)—Tungsten-Graphite Thermocouple Hot Junction End and Protecting Tubes.
Fig. 5 (Right)—Tungsten-Graphite Thermocouple Cold Junction Head and Terminals.

30. A graphite plug was drilled with a no. 40 drill for the tungsten rod and threaded on the outer diameter with a 5/16-24-N.F. thread. The junction was made by pressing the polished tungsten rod into the plug, which in turn, was screwed tightly into the graphite rod. Fig. 4 shows the construction of the hot junction. This type of dry or unwelded junction so far has proved very successful. To prevent a possible short circuit along the tube, porcelain, single-bore, insulators were used to separate the tungsten rod from the graphite tube.

31. Electrical connections at the cold junction end were made with a brass cooling head screwed tightly on the graphite tube (negative), and with a brass sleeve and set screw on the tungsten rod (positive). The assembly of the cold junction head and terminals is shown in Fig. 5. Copper wires were used for lead wires.

32.   Two different types of cooling heads have been used. The water-cooled cold junction, shown in Fig. 5, has proved most satisfactory for continuous temperature readings or temperature readings in the electric furnace. An air cooled head, equipped with a bi-metal thermometer, has proved most satisfactory for a portable unit used only occasionally. This is shown in Fig. 6.

PROTECTION TUBES

33.   The graphite element of the thermocouple was protected from oxidation by thin secondary graphite tubes. These tubes were 7-in. long and were made from 1-in. graphite electrodes, drilled and reamed ¾-in. on a turret lathe. The lower tube or tip was made with a closed end ⅛-in. thick. In molten cast iron containing about 3.50 per cent carbon, the lower protection tube lasted for 20 to 30 immersions in the ladle before it became thin enough to be discarded. The upper protecting tubes or sleeves lasted about three times as long as the immersion tubes. When the tubes became dangerously thin, they were slipped off and new ones were slipped on.

34.   The lower protecting tube was given a thin coating of RA 162 alundum cement when used in molten cast iron of low carbon content. This was accomplished by dipping the tubes, when

Fig. 6—Tungsten-Graphite Couple with Air Cooled Head.

hot, into a solution of the alundum cement, water glass, and water and holding until boiling ceased. These coated tubes lasted for 15 to 20 immersions in cast iron containing 2.80 per cent carbon.

35. Protecting tubes, for use in very low carbon cast iron and steel, were purchased. These tubes were made from a clay and graphite mixture, similar to a crucible material, and withstood the corroding action of the steel very well. The size of these tubes was 1¼-in. O.D. by ¾-in. I.D. by 8-in. long. The thermal conductivity of this material was much lower than that of graphite and could not be used to obtain rapid readings in small ladles of metal.

Calibration of the Tungsten-Graphite Thermocouple

36. The tungsten-graphite thermocouple was calibrated by the secondary or comparison method, using a calibrated platinum-platinum-10 per cent-rhodium couple for the standard.

37. The platinum-platinum-10 per cent-rhodium couple first was calibrated by the primary or freezing point method. After consulting a large number of foundrymen about temperature measurements, it was obvious that many of them want further information on this method of calibrating or checking their thermocouples. This method will be discussed only briefly here. Further detailed information can be found in an excellent booklet on pyrometry practice published by the United States Bureau of Standards[8].

Primary Calibration

38. The primary method of calibrating thermocouples consists of measuring the thermal e.m.f. at the known freezing points for pure metals. Five pure metals with definite known freezing points can be purchased from the Bureau of Standards for a nominal price. They are tin, lead, zinc, aluminum, and copper, having a temperature range up to 2000°F.

39. The pure metals are melted in a small graphite crucible in a resistance type furnace. The thermocouple with a sillimanite protecting tube is inserted in the metal and the metal allowed to cool slowly. Millivolt readings are taken at time intervals and a curve of thermal e.m.f. versus time is plotted. Fig. 7 shows the cooling curves for five different pure metals. The point where the slope of the curve becomes horizontal indicates the true freezing
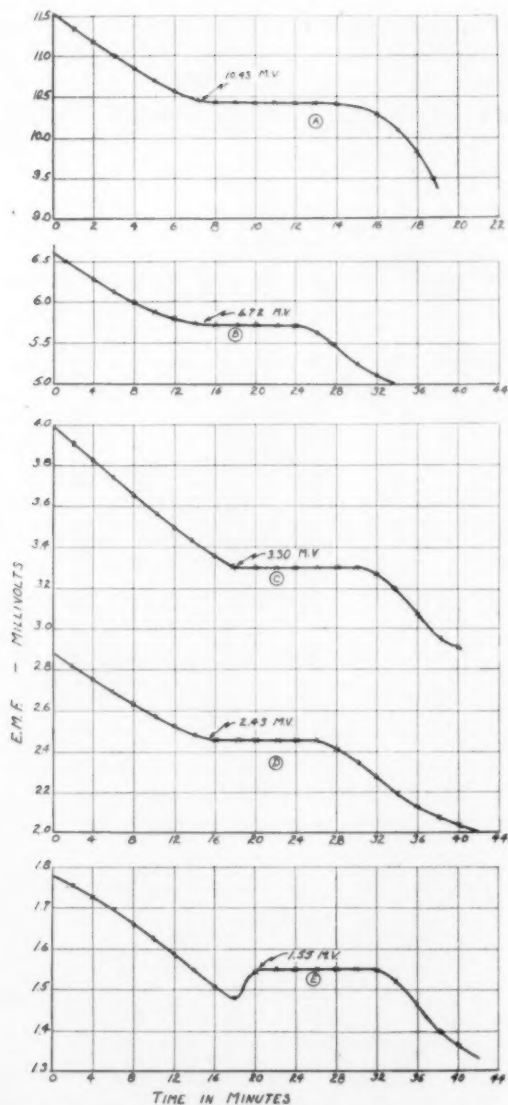
FIG. 7—FREEZING CURVES OF PURE METALS USING A PLATINUM-PLATINUM-10 PER CENT
RHODIUM *A* THERMOCOUPLE. (A) COPPER. COLD JUNCTION 20.5°C. (68.9°F.) (B) ALUMINUM.
COLD JUNCTION 21.5°C. (70.7°F.) (C) ZINC. COLD JUNCTION 25°C. (77°F.) (D) LEAD.
COLD JUNCTION 21°C. (69.8°F.) (E) TIN. COLD JUNCTION 24°C. (75.2°F.).

point. Since this temperature is known in °F. or °C., the thermal
e.m.f. for this temperature is found. These points, for the five
different metals, will determine the calibration curve for the couple
which can be extrapolated to higher temperatures.
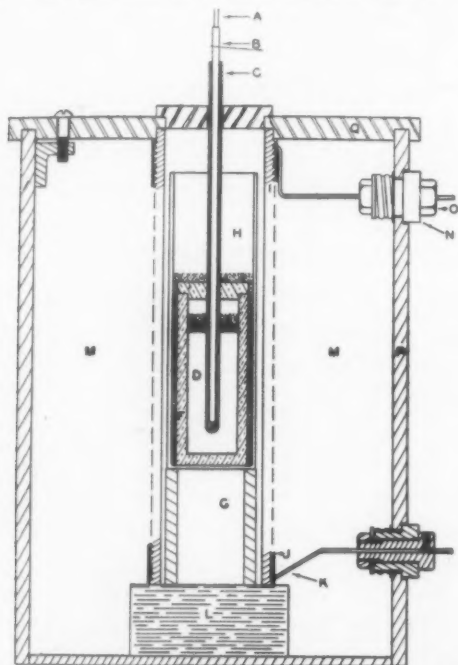
FIG. 8—FREEZING POINT FURNACE FOR METALS. (A) COUPLE WIRES. (B) INSULATING TUBE.
(C) SILLIMANITE PROTECTING TUBE. (D) BUREAU OF STANDARDS METAL. (E) GRAPHITE.
(F) GRAPHITE CRUCIBLE. (G) RA 98 ALUNDUM TUBE. (H) RA 360 ALUNDUM THIMBLE OR
CRUCIBLE. (I) CORRUGATED RA 98 ALUNDUM HEATER TUBE. (J) No. 14 CHROMEL WIRE.
(K) No. 10 CHROMEL WIRE. (L) INSULATING BRICK. (M) SIL-O-CEL INSULATING POWDER.
(N) PORCELAIN INSULATOR. (O) ONE HALF INCH BOLT. (P) EIGHT INCH PIPE. (Q) ASBESTOS
TOP.

CALIBRATION FURNACE

40.   A resistance furnace for the calibration of noble-metal
or base-metal thermocouples is shown in Fig. 8. This furnace,
which is a modification of one suggested by the United States
Bureau of Standards[8], was built at the University of Minnesota
and has proved very satisfactory for primary or secondary calibra-
tions up to 2300°F. The heater tube, made of corrugated alundum,
was 2¼-in. I.D. by 10-in. long with eight threads per inch. With
78 turns of no. 14 chromel wire, the furnace reached a temperature
of 2300°F. on 110 volts at 10 amperes. A rheostat was used for
temperature control.
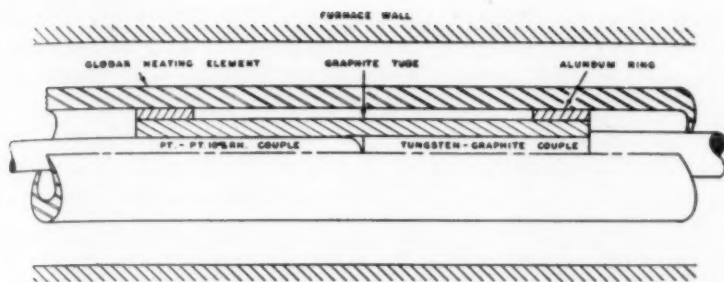
FIG. 9—METHOD OF CALIBRATION OF TUNGSTEN-GRAPHITE COUPLE.

41. The sillimanite tube was protected by a second thin graphite tube when used in the pure aluminum, as aluminum will attack the porcelain.

42. Cold junction corrections must be made if the junction of the couple wires and the lead wires are not maintained at the freezing point of water. This is true in all pyrometry work as the instrument, usually a millivoltmeter, reads only the thermal e.m.f. difference between the hot junction and the cold junction.

SECONDARY CALIBRATION

43. The tungsten-graphite couple was calibrated by comparing its thermal e.m.f. or millivolt reading with that of the platinum couple when they were both at the same temperatures. This was done by placing the two couples end to end in a graphite tube and heating them to various constant temperature levels in a Globar
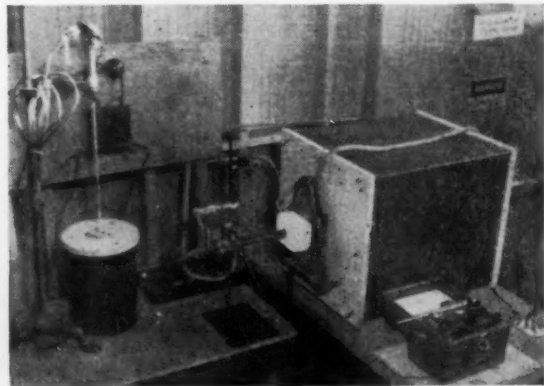
FIG. 10—APPARATUS FOR CALIBRATION OF THERMOCOUPLES. PRIMARY CALIBRATION EQUIPMENT IS SHOWN ON THE LEFT, SECONDARY CALIBRATION EQUIPMENT ON THE RIGHT.

tube resistance furnace. The location of the thermocouples in the tube is shown in Fig. 9. The cold junction temperature of the tungsten-graphite couple was taken as the water temperature flowing through the cooling head. The cold junction temperature of the platinum couple was taken as the potentiometer terminal temperature when compensating lead wires were used. The primary and secondary calibration equipment is shown in Fig. 10.
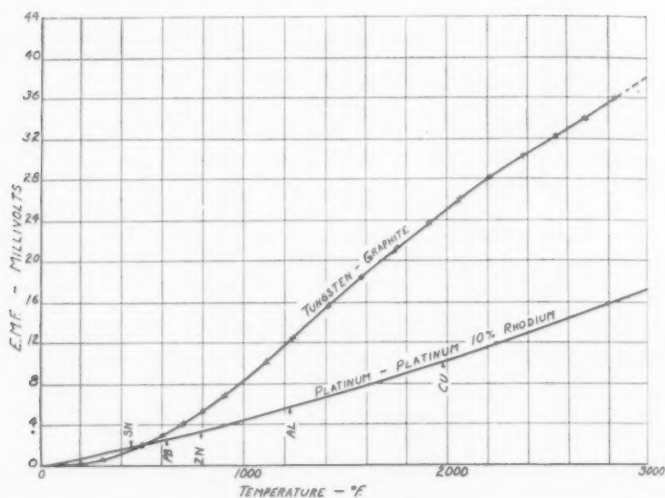
Fig. 11—Calibration Curve of Tungsten-Graphite Couple as Compared to Curve of Platinum-Platinum 10 Per Cent Rhodium Couple.

44. The tungsten-graphite couples were calibrated frequently in this manner to detect any change that might occur in calibrations. The calibration curves for a platinum-platinum-10 per cent-rhodium couple and a tungsten-graphite couple are shown in Figs. 11 and 12.

Operating Characteristics of the Tungsten-Graphite Thermocouple

45. The thermoelectric power of the tungsten-graphite couple, at 2600°F., has been more than twice that of the platinum-platinum-10 per cent-rhodium couple. Yet, the thermal e.m.f., in millivolts, was within range of the common type of potentiometer or precision millivoltmeter. This high thermal e.m.f. increased the accuracy of the temperature readings and allowed an inexpensive type of millivoltmeter to be used with one of our couples for portable use.

46.   The thermoelectric power of the couple, at room temper-
ature, was much less than that of the platinum couple. This gave
minimum cold junction corrections if the cooling head was kept
below 212°F. The water-cooled head, using water at 40 or 50°F.,
eliminated any cold junction corrections. The temperature of the
air-cooled head was determined by an attached bi-metal ther-
mometer and the necessary correction was made. Compensating
wires have been used to eliminate the necessity of measuring the
cooling head temperature. The wires used were stove pipe wire
for positive, and piano wire for negative. This low cold junction
correction has been very desirable in our experimental work.

47.   The tungsten-graphite couples were checked against a
calibrated platinum-platinum-10 per cent-rhodium couple after
every 40 immersions. Those couples, equipped with a graphite
tube which had been previously annealed at 3300°F, showed no
departure from the original calibration. Couples, equipped with
an unannealed graphite tube had an original calibration about one
millivolt lower than those made with annealed graphite. After
these couples were used at 2800°F., they showed changes in calibra-
tion approaching the calibration of the annealed couples. Upon
heating the unannealed couples to a temperature of 3300°F., their
calibration was very close to that of the annealed couple. After
annealing, all four couples had calibrations within two per cent
of each other. The millivolt reading was 42 millivolts when the
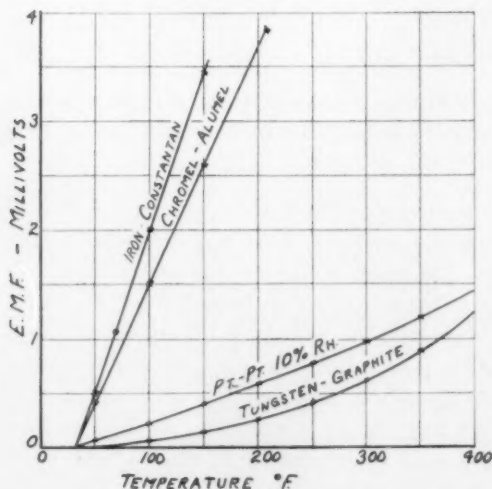
Fig. 12—CALIBRATION CURVE OF TUNGSTEN-GRAPHITE COUPLE AT LOW TEMPERATURES.
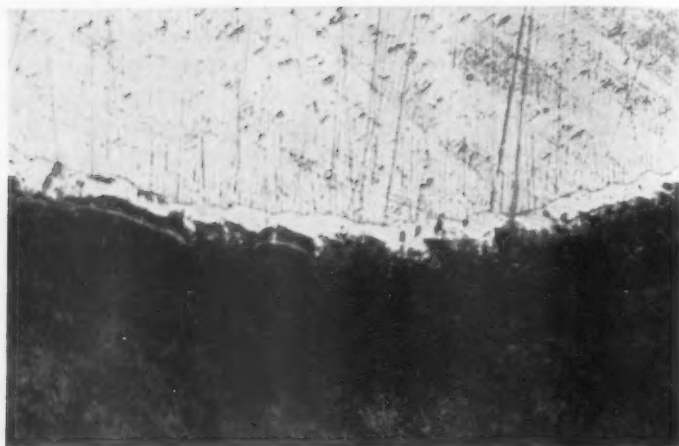
FIG. 13—PHOTOMICROGRAPH OF TUNGSTEN ROD IN GRAPHITE PLUG. AFTER 1500 MINUTES OF IMMERSION IN MOLTEN CAST IRON. WHITE UNSCRATCHED RING AROUND THE TUNGSTEN ROD IS TUNGSTEN CARBIDE. X100.

tungsten-graphite couple was at 3325°F. as measured by an optical pyrometer.

48. At 3300°F., the porcelain insulators at the hot junction as shown in Fig. 4, fused. Therefore, the construction was modified by moving the porcelain insulators about 8 in. back from the graphite plug.

49. Couples made from materials purchased in 1938 gave readings at 2600°F. about 2.3 millivolts higher than the couples used by Holbrook[7] in 1932 and Watson and Abrams[5] in 1928.

50. One of the couples has had 500 immersions, or approximately 2000 min. immersion time, with no measurable change in calibration.

51. Tungsten combines with carbon at high temperatures, forming tungsten carbide. This metallurgical change at the hot junction did not seem to affect the calibration. As long as the temperature at the hot junction is uniform throughout the diameter of the tungsten rod, the changing of tungsten to tungsten-carbide should not affect the calibration until all the tungsten rod has been changed into tungsten carbide. The amount of tungsten carbide formed at the junction of a tungsten rod and graphite plug, after about 1500 min. of immersion, is only about 0.002-in. This is shown in the photomicrograph in Fig. 13. The white unscratched ring around the rod is tungsten carbide.
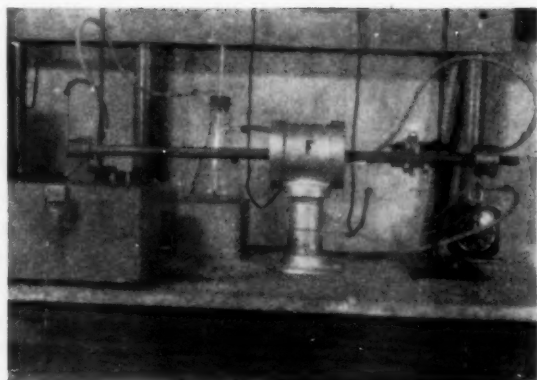
FIG. 14—HOMOGENEITY TEST OF TUNGSTEN-GRAPHITE THERMOCOUPLE.

52.   A test has been used to try to find any inhomogeneity in the materials used in these couples. This test consists of maintaining the same temperature at both the hot and cold junction of the couple and heating various intermediate points. Any change in homogeneity would be shown by a deflection of a galvanometer connected at the cold junction terminals. So far this test has not shown any inhomogeneity. Fig. 14 shows the laboratory equipment used for this test.

53.   Temperature readings in 30 lb. of molten cast iron have been taken in less than 70 sec. when the graphite protecting tubes were used. Fig. 15 shows the difference in time required to obtain readings with the various temperature measuring devices described in this paper. This data was obtained by plunging the thermocouple into a 70-lb. ladle of cast iron at a temperature of 2800°F. and taking thermocouple readings at 10-sec. intervals until the maximum temperature reading was obtained. The tungsten-graphite thermocouple was surpassed in rapid temperature readings only by the optical pyrometer in the black-body tube. The tungsten-graphite couple, with its small thermal lag, did not chill the 30-lb. ladles of cast iron below their pouring temperature. Usually, the metal had to be held in the ladle until the correct temperature was reached. The couple was immersed 4-in. and used to stir the metal. The couple was sensitive enough to show a difference 15 to 20°F. between the bottom, sides, and center of the molten metal, when the metal was allowed to remain quiet for 2 min. and the couple was moved to the various points.

54.   The couples were not harmed by thermal shock. One couple was cooled to −10°F. and then plunged into iron at 2900°F. without any harm. Nearly all our temperature readings were taken by immersion from room temperature.

55.   Temperature readings in the 30-lb. ladles of molten cast iron were taken, using the 1-in. O.D. graphite protecting tubes. These tubes were slipped on and off easily. The uncoated tube lasted very well in cast iron of 3.50 per cent carbon. The outside diameter of the graphite tube was decreased more by oxidation in air than by dissolving in the metal. The coated tubes lasted much longer than the uncoated tubes, when used in low carbon cast iron. A coated tube did not change in diameter when held in cast iron of 2.32 per cent carbon for 4-min. at 2600°F. and did not change the carbon analyses of the metal. A bare graphite tube decreased from an original diameter of 1.004 in. to a diameter of 0.959 in. when left in cast iron of 2.32 per cent carbon for 4-min. at 2600°F. Analysis of the iron was changed to 2.37 per cent carbon. No difference was noticed in time required to obtain these readings as the alundum coating was very thin.

56.   One of these tungsten-graphite immersion type thermo-couples, with an uncoated graphite protecting tube, has been used to measure temperatures in molten bronze and aluminum with satisfactory results.

CONCLUSIONS

57.   Four immersion-type, tungsten-graphite, thermocouples have been built and used at the University of Minnesota foundry to measure temperatures of the cast iron poured into test bars. Two of the thermocouples have been used for 4 months.
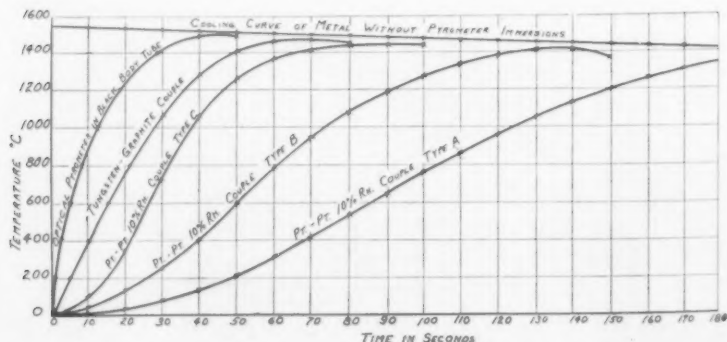
FIG. 15—TIME REQUIRED TO OBTAIN READINGS WITH VARIOUS TYPES OF PYROMETERS.

58.   The results obtained from the use of the tungsten-graphite immersion type thermocouple have proved the following advantageous features:

(1)   Temperature measurements can be made up to at least 3300°F.

(2)   Temperature measurements in small ladles of metal can be obtained more rapidly than with a protected platinum-platinum-10 per cent-rhodium couple.

(3)   Temperature measurements are unaffected by the presence of smoke or slag.

(4)   The thermal e.m.f. is higher than that of any other commercial thermocouple having a negligible cold junction correction.

(5)   The size of this couple can be made smaller than that of other high temperature couples.

(6)   The material cost is lower than that of a platinum-platinum-10 per cent-rhodium thermocouple.

(7)   The protection tubes for immersion use in molten cast iron are low in cost and are not affected by thermal shock.

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Sixty Thousand Pound Per Square Inch Cupola Iron

By E. L. ROTH,* MILWAUKEE, WIS.

Abstract

The procedure for producing iron having 60,000 lb. per sq. in. tensile strength in his company's foundry is described by the author. Cupola operation which produces an average total carbon analysis of 3.10 per cent is detailed. This practice gives good machinability in castings as small as 3 lb. in weight. Physical properties and chemical analysis are given of 64 consecutive heats as well as the effect of heating and quenching the material in oil. Some representative applications are illustrated and discussed.

INTRODUCTION

1. Most discussions on high strength cast irons have centered around iron having a carbon content well below 3.00 per cent. Starting in 1930 an iron of 50,000 lb. per sq. tensile strength was produced while maintaining the carbons at an average of 2.80 per cent.

2. This type of iron, regardless of alloy content, presents many casting problems. It becomes quite hard and machines with difficulty in small and medium size castings thereby limiting its applications. A requirement for A.S.T.M. class 60 iron in brake drums weighing 140 lb. led us to the development of a base iron having an average carbon content of 3.10 per cent (74 ladles) from which commercially machinable castings as light as 3 lb. are being produced. Each heat consisted of one to three 1600 lb. ladles of iron which were poured into commercial castings. This is mentioned to bring out the point that the data shown in Table 1 do not represent a set of laboratory experiments.

MELTING PRACTICE

3. The cupola is 48 in. inside diameter with a 3 in. continuous tuyere having 18 in. blocked off in both the front and rear of the

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Table 1

DATA ON HIGH STRENGTH CUPOLA IRONS BEING RUN COMMERCIALLY

Heat No.	Transverse† Strength lb. per sq. in.	BHN Center of 1.2 in. Test Bar	Tensile†† Strength lb. per sq. in.	% T.C.	% Si	% P	% Mn	% S	% Cr	% Mo	% Ni
940	6000	269	65,710	3.07	1.94	0.102	0.76	0.072	0.33	0.68	1.69
941	6220	277	66,910	2.95	2.01	0.104	0.70	0.070	0.27	0.70	1.72
942	6000	269	65,550	3.14	1.89	....	....	....	....	....	....
943	6500	269	67,100	3.01	1.99	0.108	0.85	0.073	0.28	0.67	1.61
944	6010	269	64,710	3.09	1.89	....	....	....	0.34	0.67	1.83
950	6000	269	60,620	3.15	1.96	....	....	....	....	....	....
951	6500	302	61,790	3.20	1.83	....	....	....	0.28	0.67	1.59
953	5124*	248	62,890	3.25	2.22	....	....	....	0.31	0.69	1.67
954	Flaw	332	64,610	3.11	2.04	....	....	....	....	....	....
955	5370	387	66,200	3.08	1.83	....	....	....	....	....	....
956	5195	269	62,420	3.22	1.83	0.114	0.81	0.075	0.35	0.60	1.31
957A	5340	293	74,330	3.09	1.62	....	....	....	....	....	....
957B	5705	262	66,360	3.15	1.83	....	....	....	....	....	....
958	5190	248	62,110	3.11	1.87	....	....	....	....	....	....
959A	5745	302	69,900	3.12	1.83	....	....	....	0.23	0.75	1.64
959B	5565	255	71,290	3.19	1.86	....	....	....	....	....	....
959C	6095	262	61,470	3.13	2.04	....	....	....	0.29	0.59	1.11
960A	5912	269	71,190	3.01	1.62	....	....	....	....	....	....
960B	6315	269	63,840	3.08	1.80	....	....	....	0.27	0.70	1.54
961A	5340	286	72,050	3.09	1.60	....	....	....	0.24	0.69	1.52
961B	6047	255	62,400	3.10	1.63	....	....	....	0.24	0.52	0.83
961C	5465	248	61,360	3.04	1.94	....	....	....	....	....	....
962A	5710	302	75,140	2.96	1.65	0.092	0.88	0.081	0.27	0.75	1.52
962B	5680	241	60,790	3.08	1.92	....	....	....	....	....	....
963	5935	269	60,000	3.16	1.88	....	....	....	0.29	0.73	1.53
971	6300	277	69,010	3.19	1.99	....	....	....	....	....	....
972	6150	286	77,680	3.14	2.01	....	....	....	....	....	....
975	5360	262	61,430	3.22	2.05	....	....	....	....	....	....
976	5220	255	58,890	3.26	2.10	....	....	....	0.37	0.63	1.82
977	5230	262	61,880	3.22	2.02	....	....	....	0.29	0.68	1.83
982	5450	269	65,040	3.10	1.80	....	....	....	....	0.63	....
989	5150	302	61,550	3.19	2.03	....	....	....	....	....	....
990	5170	269	60,380	3.22	1.98	....	....	....	0.33	0.79	2.00
991	6010	262	64,340	3.18	1.85	....	....	....	....	....	....
992	5340	277	64,970	3.24	1.63	0.109	0.86	0.066	0.26	0.75	1.61
993	5590	277	69,030	3.16	2.08	....	....	....	....	....	....
994	5460	269	63,460	3.18	2.31	....	....	....	....	....	....
995	5220	262	63,200	3.24	2.13	0.087	0.87	0.059	0.32	0.63	1.69
996	5810	269	66,120	3.08	1.96	....	....	....	....	....	....
997	5745	286	68,710	3.19	2.19	....	....	....	....	....	....
998	5635	269	61,910	3.14	2.08	....	....	....	....	....	....
999	6100	269	66,260	3.15	2.08	0.089	0.87	0.056	0.33	0.76	1.74
1000A	5835	302	76,500	3.06	1.94	0.054	1.10	0.058	0.25	0.74	1.44
1000B	5690	269	65,920	3.22	1.88	0.058	1.02	0.054	0.27	0.77	1.29
1001	5240	262	60,680	3.08	2.19	....	....	....	0.32	0.62	1.70
1004	5760	286	65,930	3.24	1.92	0.080	0.96	0.062	0.34	0.70	1.47
1005	5650	255	61,250	3.26	2.10	....	....	....	....	....	....
1006	Flaw	269	62,230	3.23	2.01	....	....	....	....	....	....
1007	5490	262	64,330	3.27	2.01	....	....	....	....	....	....
1008	5640	269	66,960	3.18	1.88	....	....	....	....	....	....
1009	5715	262	70,020	3.14	1.73	....	....	....	....	....	....
1010	5860	277	64,690	3.20	1.79	....	....	....	....	....	....
1011A	5990	286	79,140	2.94	1.78	0.080	1.00	0.054	0.28	0.79	1.62
1011B	5940	286	75,600	2.93	1.84	0.091	0.89	0.055	0.29	0.68	1.48
1012A	6000	293	73,290	2.99	1.58	0.101	0.83	0.082	0.30	0.89	1.63
1012B	5870	286	72,490	3.02	1.62	0.107	0.97	0.073	0.26	0.84	1.42
1013A	6200	293	76,360	3.02	1.76	0.095	0.98	0.093	0.24	0.82	1.46
1013B	6050	269	73,190	2.99	1.81	0.103	0.86	0.075	0.29	0.81	1.53
1016	5930	302	77,000	3.12	1.74	0.080	0.92	0.084	0.28	0.90	1.63
1017	5770	269	67,420	3.24	1.87	0.089	0.84	0.066	0.28	0.80	1.56
1018	6120	293	70,360	3.28	1.88	0.072	1.09	0.064	0.26	0.73	1.55
1025	5765	277	67,630	3.12	2.00	0.101	0.95	0.078	0.30	0.71	1.41
1026	5830	277	70,640	3.15	1.89	0.082	0.96	0.080	0.27	0.79	1.45
1027	5220	248	56,760	3.36	2.04	0.105	0.87	0.063	0.29	0.74	1.52
1029	5640	262	66,120	3.24	1.75	0.087	0.93	0.057	0.25	0.82	1.42

(Table 1—*Continued*)

Heat No.	Transverse† Strength lb. per sq. in.	BHN Center of 1.2 in. Test Bar	Tensile†† Strength lb. per sq. in.	% T.C.	% Si	% P	% Mn	% S	% Cr	% Mo	% Ni
1030	5810	302	69,400	3.13	1.51	0.082	0.83	0.084	0.27	0.78	1.59
1031	5840	......	63,420	3.06	2.09	0.105	1.01	0.068	0.25	0.66	1.44
1033	5280	269	63,340	3.24	1.99	0.093	1.00	0.067	0.19	0.73	1.52
1034	5335	262	65,530	3.20	1.97	0.089	0.93	0.064	0.19	0.74	1.53
1035	5340	262	59,700	3.24	1.93	0.093	0.81	0.064	0.21	0.73	1.43
1036	5450	269	67,850	3.16	1.75	0.099	0.89	0.079	0.21	0.72	1.59
1037	5525	269	70,340	3.13	1.71	0.091	0.92	0.062	0.26	0.68	1.51
1038	5785	286	74,910	2.97	2.01	0.087	0.93	0.069	0.29	0.77	1.63
1039	5575	248	61,030	3.21	1.85	0.087	0.85	0.056	0.24	0.78	1.61
1040	5685	269	69,460	3.09	1.92	0.089	0.93	0.057	0.13	0.74	1.61

† Test made on 1.2 in. bar broke on 12 in. center.
†† Test made on 0.80 in. standard A.S.T.M. bar.
* Starting with heat No. 953 all the bars were corrected to 1.2 in diameter for the transverse strength test.

cupola. The lower edge of the tuyeres is 12 in. above the sand bottom.

Coke

4.   Each car of coke is inspected for physical appearance, hardness, and size and is stored in a shed having a waterproof roof to eliminate excessive moisture. Occasional checks are also made of the chemical analysis.

5.   A 48 in. coke bed was found to produce the higher total carbon required. A charge of 1800 lb. of coke is placed in the cupola and burned through with a natural draft for about 1 hr. The bed is then burned completely through with forced draft from the blower for 1 to 2 min. and is then checked for height and, if necessary, a few shovels of coke are added to produce a level bed 48 in. in height. Tuyeres are kept closed while the cupola is being charged, with the exception of the one near the slag hole.

Charging

6.   A dummy base charge of 1200 lb. return high strength iron scrap is placed on the bed coke. One hundred eighty-five pounds of coke is used between charges the weights of which are shown in Table 2.

Table 2

WEIGHT OF CHARGES USED IN CUPOLA

1360 lb. steel rail, 12 in. long or less
 195 lb. return high strength iron scrap
  45 lb. silicon briquets
  12 lb. manganese briquets

1612 lb. total

Half of the steel rail is placed on the coke, the silicon and manganese briquets charged in the center of the cupola, then the other half of the steel rail is charged and the return scrap placed on top to level the charge off.

7.   A coke split of 250 lb. is placed on top of the last high strength charge. After this coke split, the steel of the next charge is placed first in the cupola. We believe this serves two purposes:

   (1)   Steel being slower to melt retards possibility of dilution.

   (2)   If any dilution does take place a steel dilution is most desirable.

The cupola is then completely charged to the door.

Cupola Operation

8.   The time the base tap is charged in the cupola is closely checked and is considered the start of the "soaking period." The best results are obtained with a 1 hr. "soaking period" although this may run to 75 min. without encountering trouble due to the bed burning out.

9.   A weighed amount of air is used and 20 min. after the wind is put on the tap hole is opened for the base tap which is pigged. A $1\frac{1}{4}$ in. tap hole is used which permits a long enough interval for adding the spout alloys and is one of the factors controlling the ultimate total carbon content.

10.   Time between taps is recorded from the time the tap hole is opened until the tap hole is again opened. This time between taps for our high strength iron is about 7 min.

Ladle Additions

11.   The dummy charge is not poured into castings but is pigged separately. In addition to starting the melting operation it also helps to further heat up the receiving ladle which has been preheated with a blow torch. The "F" nickel is added to the ladle in 5 lb. pigs which have also been preheated. The ferromolybdenum and 80 per cent 10 mesh ferrosilicon are added, through the generally accepted funnel into the spout, after the ladle is about one third full. The amount of ferrosilicon, to produce good machinability, is varied depending upon the weight and section of casting to be poured. Varying amounts of 70 per cent 10 mesh ferrochromium

FIG. 1—BRINELL HARDNESS OF 5 IN. DIAMETER SOLID BAR 14 IN. LONG.

are also added with the above through the spout depending on the application.

ANALYSIS AND PHYSICAL PROPERTIES

12.   A series of consecutive heats is shown in Table 1. The average tensile strength of the 64 heats was 66,588 lb. three heats giving tensile strengths lower than 60,000 lb. per sq. in. They are heat No. 976, total carbon 3.26 per cent, heat No. 1027, total carbon 3.36 per cent, No. 1035 total carbon 3.24 per cent. Investigation showed that on heat No. 1027 the bed was too high not being measured correctly before charging.

13.   Some standard 0.875 in. bars were poured but as these bars were unmachinable no tensile tests could be taken. The Brinell hardness ran from 340 to 375.

14.   The Brinell hardness obtained on the cross section of a 5 in. diameter solid bar 14 in. in length is shown in Fig. 1.

POURING TEMPERATURE

15.   Castings must be poured as hot as possible in order to obtain the maximum physical properties as noted by MacPherran[1].

16.   All of the test bars are poured from a 60 lb. hand ladle which is filled from a 1600 lb. ladle before it goes to the conveyor or the molding floor. Pouring temperatures of brake drums on the conveyor run from a maximum of 2720°F. to a minimum of 2575°F. Temperature checks of test bar pouring temperatures average about 2640°F. For one test bar the hand ladle was held until the temperature dropped to 2475°F. The tensile bar pulled 49,640 lb.

[1] MacPherran, R. S., "Cupola High Test Cast Iron," Transaction A.F.A., vol. 45, 1937, pp. 343-355.

FIG. 2—CHART SHOWING EFFECT OF DRAW TEMPERATURES AFTER QUENCHING IN OIL AT 1550°F.
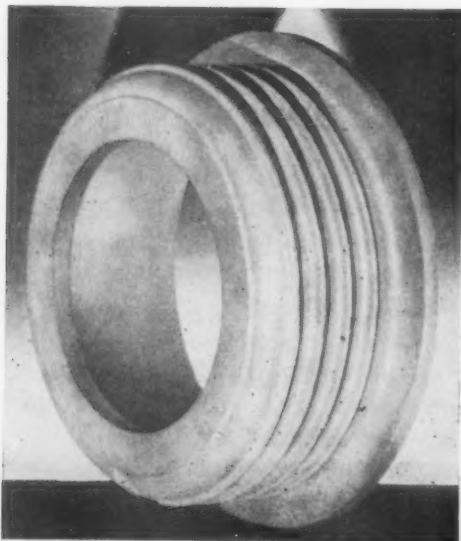
FIG. 3—BRAKE DRUM CASTING—WEIGHT 188 LB.

17.   Spout temperatures of this iron taken over a 1 yr. period
show a maximum of 2850°F. and a minimum of 2810°F.

HEAT TREATMENT

18.   A series of bars were cast from heat No. 941 and the re-
sults obtained are shown in Fig. 2. A special bar having no threads
on it was used for the heat treated tensile specimens. Three of
these broke in the grips instead of the reduced 0.80 in. section
indicating that infinitesimal cracks may have developed during the
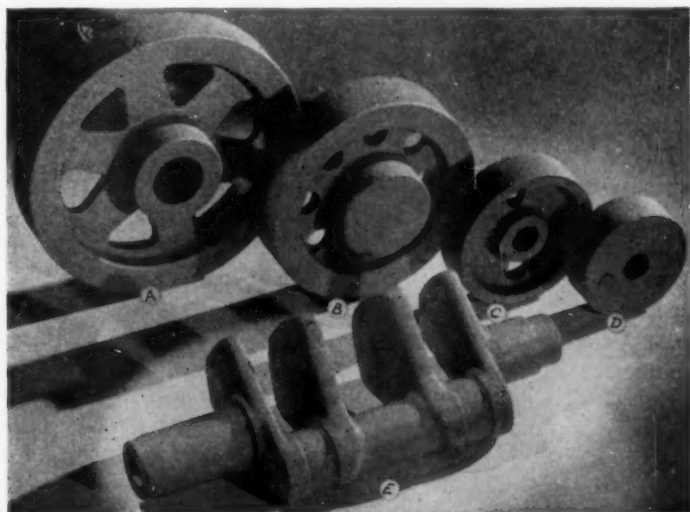
FIG. 4—SMALL CASTINGS POURED FROM 60,000 LB. IRON. (A) WEIGHT 16 LB., (B) WEIGHT
12 LB., (C) WEIGHT 6 LB., (D) WEIGHT 3 LB., (E) WEIGHT 17 LB.

quenching operation. They were the "as quenched" bar, the bar
drawn at 700°F. and the bar drawn at 800°F.

19.   The bars were heated up to 1550°F., soaked 10 min. and
then quenched in oil and drawn at the temperatures shown for 1
hr. A maximum tensile strength of 91,600 lb. was obtained with
the 600°F. draw. Further investigation may show a higher strength
at some draw temperature between 600 and 700°F. A maximum
hardness of 54.3 Rockwell "C" was obtained. Hardness readings
were the average of ten readings taken on the end of the test bars.

20.   Some typical applications of this high strength iron are
shown in Figs. 3, 4, and 5. The brake drum shown in Fig. 3 weighs
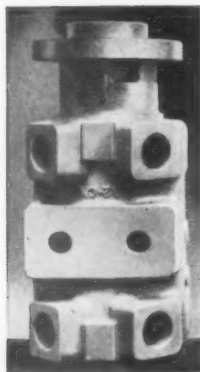
FIG. 5—HIGH PRESSURE REFRIGERATION CYLINDER—WEIGHT 875 LB.

138 lb. A section was taken out of the braking surface on one drum
poured from heat No. 1039. A 0.505 in. tensile bar was machined
from this and showed a strength of 62,850 lb. per sq. in., the Brin-
ell hardness of the casting being 248. In Table 1 note the test bar
from heat No. 1039 pulled 61,030 lb. per sq. in. with a Brinell
hardness of 248. This same check was made previously on heat
No. 933 (before tensile tests were pulled on each heat). A 0.505 in.
bar machined from the casting produced a tensile of 62,750 lb. per
sq. in. The Brinell hardness check of the casting being 269.

Table 3

BRINELL HARDNESS OF TYPICAL CASTINGS POURED

Name	Wt. Lb.	Brinell Hardness
Gear	3.0	255 to 262
Gear	3.3	241 to 269 (Fig. 4.)
Camshaft	4.8	269
Camshaft	6.6	262 to 269
Tractor Gear	15.7	269
Crankshaft	17.0	262 to 269 (Fig. 4.)
Valve Body	20.6	262
5 in. dia. bars		
(14 in. length)..	85.0	212 to 223
Brake drum	138.0	248 to 269 (Fig. 3.)

21. The smallest casting made to date of this material is a
gear weighing 3 lb. shown in Fig. 4. These are cast four in a mold
from a plate pattern and the teeth are cut on gear hobbers. The
largest castings poured from this material to date weighed 1175 lb.
and in this case the silicon was dropped to 1.50 per cent. The

practice is to vary the silicon, depending on the weight and section of the casting, from 1.50 to 2.50 per cent. The chromium addition range from 0.15 to 0.40 per cent depending on the size of the casting and the particular application.

MACHINABILITY

22.   The requirement for a high strength brake drum iron which had a comparatively high total carbon was based on the theory that higher carbon irons do not heat check as readily in heavy duty truck service as lower carbon irons. This higher carbon, we feel, is the main factor in the good machinability obtained. It
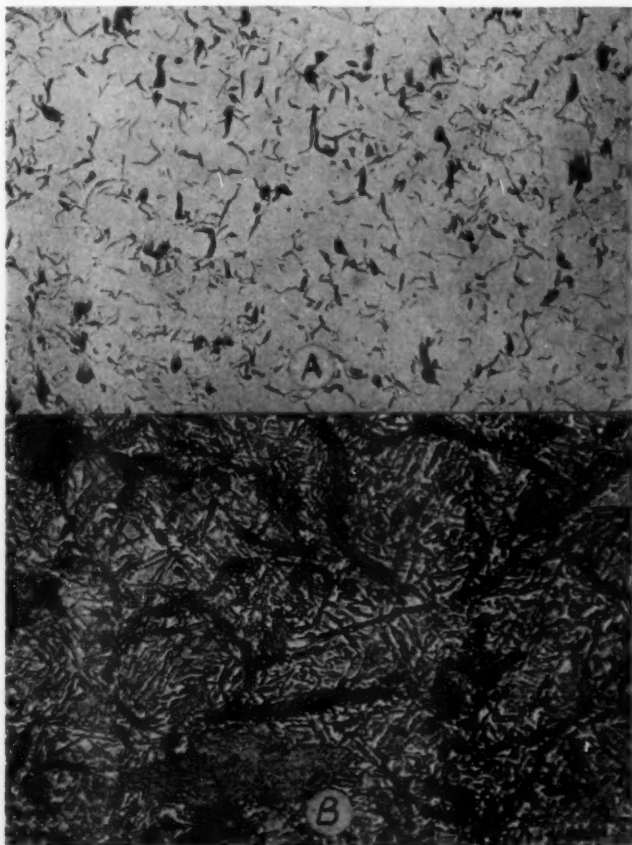
FIG. 6—(A) UNETCHED (x 100.) (B) ETCHED NITAL (x 500.) HEAT NO. 995, 63,200 LB. PER SQ. IN. TENSILE STRENGTH, TOTAL CARBON 3.24 PER CENT, SILICON 2.13 PER CENT, MOLYBDENUM 0.63 PER CENT, NICKEL 1.69 PER CENT.
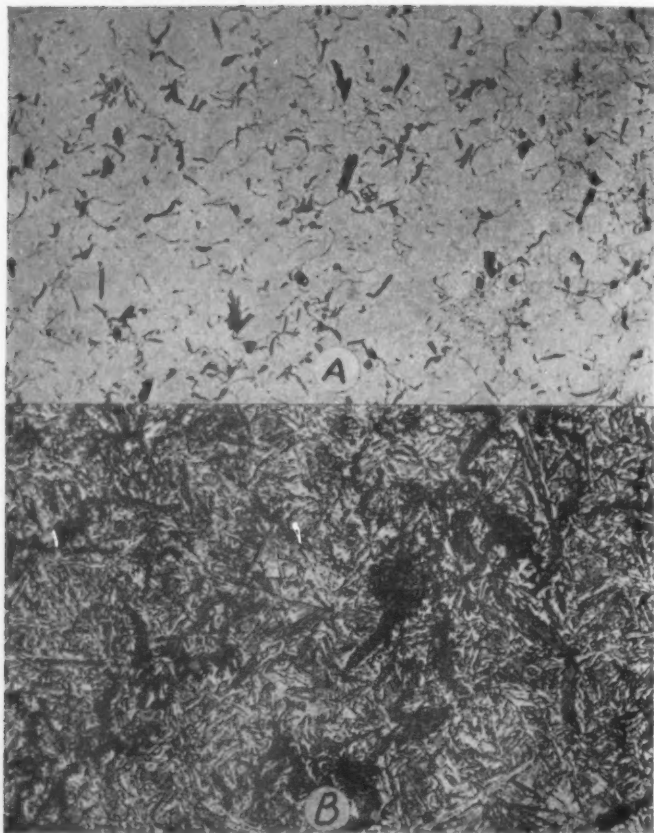
Fig. 7—(A) Unetched (x 100.) (B) Etched nital (x 500.) Heat No. 1016, 77,000 lb. per sq. in. tensile strength, total carbon 3.12 per cent, silicon 1.74 per cent molybdenum 0.90 per cent, nickel 1.63 per cent.

was also found that the nickel content should not go below 1.40 per cent and preferably up to 1.75 per cent on the smaller castings.

23.   At the present time the brake drums shown in Fig. 3 are being machined at a speed of 60 ft. per min. with tool steel using a coolant. The smallest speed reducer gears go through all the machining operations without difficulty but the machine shop states they are "tough iron." This is more than compensated for by the service life on this gear which is over four times that of a so-called semi-steel gear.

CONCLUSION

24. This material may be substituted for steel castings and forgings due to its much greater wear resistance and good machinability. It must be remembered the tensile strength is also practically the elastic limit so that for static loads the material is actually stronger in many cases even in tension. The brake drum application illustrated in Fig. 3 has the driving sprocket bolted to the brake drum and is replacing a steel casting. In crankshaft applications the casting can be made close to size thereby reducing machine costs and the greater damping capacity is also an advantage.
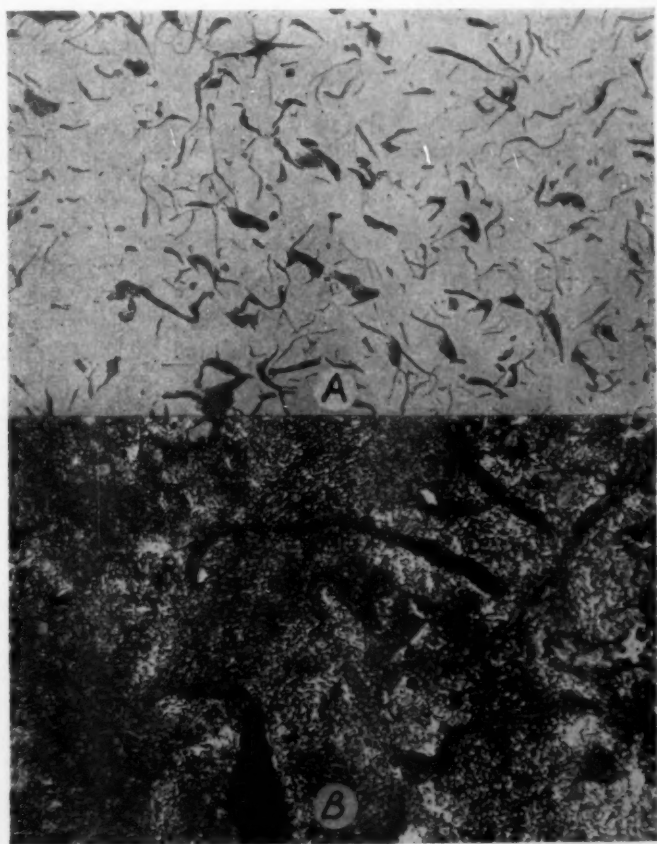
FIG. 8—(A) UNETCHED (X 100.) (B) ETCHED NITAL (X 500.) HEAT NO. 1039, 61,030 LB. PER SQ. IN. TENSILE STRENGTH, TOTAL CARBON 3.21 PER CENT, SILICON 1.85 PER CENT, MOLYBDENUM 0.78 PER CENT, NICKEL 1.61 PER CENT.

Table 4

STANDARD ANALYSIS OF 60,000 LB. PER SQ. IN. IRON

```
Silicon .....................1.60 to 2.20 depending on section
Total Carbon ..............2.95 to 3.25
Manganese ................0.70 to 0.90
Phosphorus ...............0.12 max.
Sulphur ...................0.090 max.
Nickel ....................1.50 to 1.75
Chromium .................0.15 to 0.35
Molybdenum ...............0.70 to 0.80
```

25.   From results to date it is felt that by holding the carbon to closer limits say 2.90 to 3.05 per cent with a molybdenum content of 0.75 to 0.85 per cent a 70,000 lb. per sq. in. minimum tensile strength iron could be produced.

26.   The average analysis used as a standard to produce maximum machinability with a 60,000 lb. per sq. in. minimum tensile strength is shown in Table 4.

ACKNOWLEDGMENT

27.   The writer wishes to acknowledge the co-operation of J. V. Olle of our organization in developing this material. He also wishes to thank J. S. Vanick of International Nickel Company for pulling the heat treated tensile specimens.

DISCUSSION

Presiding: W. R. JENNINGS, JOHN DEERE TRACTOR CO., WATERLOO, IOWA.

CHAIRMAN JENNINGS: We have heard about 40,000 and 50,000 lb. per sq. in. iron, and now we have 60,000 lb. per sq. in. iron. Many of us have made it, or tried to make it, and a good share of the time I would say we were successful, depending upon the accuracy of our equipment and our control. Mr. Roth is to be congratulated upon his paper, citing as he does 75 examples of 60,000 lb. per sq. in. iron and higher.

MR. ROTH: In talking to one foundryman about this paper, he asked: "Do you use a commercial grade of coke?" My answer is, "Yes." But we have found large variations in our results from different producers. Those here who attended the recent Milwaukee Regional Conference, when coke was discussed, probably have a good picture of the reasons for variations in coke qualities.

M. G. CORSON[1] *(Written discussion):* Sixty thousand lb. per sq. in. tensile strength in a cupola iron certainly is a rather high figure, especially when the total carbon content is so close to 3.15 per cent. which can be obtained without much difficulty in a cupola. Lower total carbon figures correspond mostly to products of more costly melting processes. Mr. Roth ought to say 66,000 lb. per sq. in., for this figure is much closer to the average according to the total number of ladles investigated. Forty eight per cent of his samples possessed a tensile strength in excess of 66,000 lb. per sq. in.

The writer has tried to correlate the physical characteristics of the irons with their chemical compositions in regard to the content of total carbon, chromium, molybdenum and nickel. To this end, he retabulated Mr. Roth's data in two manners: First, in order of increasing tensile strengths and, second, in order of increasing hardnesses. Then he averaged the values and computed the percentage frequency with the given ranges of tensile strength and Brinell hardness which occurred during Mr. Roth's production tests. Tables 4 and 5 show the results of the retabulation.

It becomes evident from these two tables that:

(1) There is no true correlation between tensile strength and hardness.

(2) There was extremely little correlation between tensile strength and total carbon. What correlation might exist is so slight that it is beyond the possibility of adjusting

Table 4

TENSILE STRENGTH CORRELATIONS

Ultimate Strength, lb. per sq. in.	Brinell Hardness No.	Total C. Per Cent	Cr. Per Cent	Mo. Per Cent	Ni. Per Cent	Frequency, Per Cent
Up to 60,000	250	3.31	0.35	0.70	1.65	2.7
Up to 61,000	260	3.14	0.30	0.75	1.75	6.7
Up to 62,000	260	3.18	0.30	0.70	1.55	12.0
Up to 63,000	260	3.18	0.30	0.60	1.60	6.7
Up to 64,000	270	3.16	0.25	0.70	1.55	6.7
Up to 65,000	270	3.18	0.30	0.70	1.70	8.0
Up to 66,000	270	3.16	0.25	0.70	1.50	9.3
Up to 67,000	270	3.12	0.30	0.75	1.70	9.3
Up to 68,000	270	3.13	0.30	0.70	1.55	5.3
Up to 69,000	280	3.19	...	...	...	2.7
Up to 70,000	285	3.00	0.25	0.80	1.65	9.3
Up to 71,000	280	3.19	0.25	0.70	1.50	4.0
Up to 72,000	270	3.10	0.25	0.70	1.50	4.0
Up to 75,000	285	3.00	0.30	0.80	1.60	6.7
Over 75,000	295	3.00	0.25	0.80	1.65	9.3

[1] Consulting Metallurgist, New York City.

Table 5

BRINELL HARDNESS CORRELATIONS

Brinell Hardness No.	Ultimate Strength, lb. per sq. in.	Total C, Per Cent	Cr. Per Cent	Mo. Per Cent	Ni. Per Cent	Frequency, Per Cent
241	60,800	3.08	. . .	. . .	. . .	1.3
248	60,800	3.19	0.30	0.75	1.60	6.8
255	63,500	3.20	0.30	0.60	1.30	5.4
262	63,700	3.19	0.30	0.70	1.75	16.2
269	65,500	3.14	0.25	0.75	1.70	32.4
277	67,500	3.15	0.25	0.75	1.55	9.4
286	73,300	3.07	0.30	0.75	1.70	10.9
293	73,600	3.09	0.25	0.80	1.55	5.4
302	70,000	3.11	0.30	0.75	1.70	9.5
332	64,600	3.11	. . .	. . .	. . .	1.3
387	66,200	3.08	. . .	. . .	. . .	1.3

the carbon content to the tensile strength desired in the foundry.

(3)   There is no correlation whatsoever between the contents in chromium, molybdenum and nickel used and the tensile strength and hardness obtained.

The conclusion must be therefore that:

(1)   In all probability the results (high strength) obtained were due to the peculiar raw material used. For example steel rail scrap composing about 85 per cent of the total charge.

(2)   If the additions of chromium, molybdenum and nickel had a beneficial action (this is not proved) its acme was reached at much lower additions, the excessive amounts causing but an indefinite effect.

And further we might observe that:

(3)   The process used does not adapt itself to the production of castings of uniform hardness. So, had the castings been ordered for parts where wear resistance is important, those of less than 270 Brinell might have been rejected (fully 30 per cent). On the other hand, if machinability were of great importance, those with 280 Brinell and over certainly would cause the machinists to weep and complain bitterly. There were 29 per cent of such high-hardness heats.

Finally, the writer should express his disappointment caused by the complete absence of the graphitic carbon data, as well as photomicrographs, for without these two, one cannot form any idea concerning the nature of the cast irons studied or used.

Talking about 60,000 lb. per sq. in. cast iron brings the writer to consider other cases of high and lower high-test irons. I am presenting therefore, two micrographs (Fig. 9) showing typical structures of two such irons, one of 60,000 and one about 45,000 lb. per sq. in. tensile strength. As can be seen from the micrographs shown, the weaker iron (B of Fig. 9) had much finer (as far as thickness goes) flakes of graphite, than the stronger one. Having measured the ratios of length to thickness of 20 flakes, taken at random in sections of both irons, the writer found the ratio of 44 in the weaker iron and of 32 in the stronger one. Both irons were well made and their porosity did not reach 1 per cent (0.8 per cent in the stronger, 0.6 per cent in the weaker iron). The stronger contained 1.05 per cent, the weaker 0.77 per cent combined carbon and the stronger contained 2.07 per cent, the weaker 2.38 per cent graphite.

From the writer's studies of various cast irons, he developed the following formula for the purpose of computing the tensile strengths of cast irons (also malleables) from the analytical and micrographical data:

$P = 10AB$ where

$A = (38 + 170C - 133C^2 + 36C^3)$ and $B = (68 - 1.05R + 0.0089R^2 - 0.0000285R^3 + \dfrac{1330 - 400Gr.}{41.5 + Gr.})$ where

C = percentage of the combined carbon,

Gr. = percentage of graphitic carbon,

R = the ratio of the length to the thickness of the flakes of graphite.

Using this formula, the tensile strength of the high test iron was computed to be 62,600 lb. per sq. in. and of the medium test, 47,800 lb. per sq. in. The difference of 14,800 lb. per sq. in. or 23.6 per cent was caused by:

0.28 per cent less combined carbon—loss of 4.7 per cent

0.31 per cent more graphitic carbon—loss of 5.0 per cent

12 units higher ratio L/D—loss of 13.9 per cent

This shows that the relative dimensions of the flakes of graphite form the most potent factor affecting the tensile strength.

I wonder if Mr. Roth and other gray-iron foundrymen would care to try this formula on their products. So far I found that it is precise to plus/minus 3 per cent in the case of gray iron and malleable, and to −5 per cent (too high) in the case of cast steel (unalloyed.)

MR. ROTH: In reply to Mr. Corson, unfortunately, we do not have a photomicrographic outfit. We sell castings to the customers, so that we can not take our bars and have them run down in order to find the dimensions of the graphite flakes.

R. S. MacPherran, at a meeting in Milwaukee 2 years ago, defined the percentage of combined carbon as the sum of two errors. I feel

the same way about it. So far as the castings go, their hardness is quite uniform. The hardness figure as given in Table 1, which Mr. Corson referred to, is the hardness of test bars, 15 in. long, weighing 5 lb. The hardness of those bars varies with the pouring temperature. One can appreciate when a man is carrying a 60-lb. hand ladle over to some molds, if he is delayed, say, 5 sec., the temperature drops and there is a different hardness reading in your test bar and core.

The smallest castings we have made to date are 3-lb. gears. They are poured four at a time and with the sprue, risers and gates, there is a total of 18 lb. of iron in that mold. This affords an opportunity for the annealing action to help produce a more uniform hardness in the actual casting than one would imagine possible according to the variation hardnesses obtained in the test bars shown in Table 1.

MEMBER: Mr. Roth, how were these test bars poured, horizontal or vertical?

MR. ROTH: The test bars were poured vertically and the specimen taken from the lower half. We have found that results from the upper half and the lower half of the bar on a vertically poured piece check quite closely, but that in the 6 in. center of an 18-in. bar we get lower tensile strengths. Why that is, I do not know. For instance, here at the center of an 18-in. bar we got 48,100 lb. per sq. in. The lower third of it ran 62,200 lb. per sq. in. In another case at the center of the bar we got 59,660 lb. per sq. in.; in the lower half of the bar, 62,120 lb. per sq. in.

MEMBER: In our experience, we have found as much as 10,000 lb. per sq. in. tensile strength difference between the lower section and the upper section. The impact strengths are exactly reversed, the higher impact at the top of the bar and the lower impact at the bottom. Of course, the higher the strength of the iron the investigator is working with, the larger the difference between the two sections. With the weaker iron, around 30,000 or 40,000 lb. per sq. in., there is not nearly as great a difference between the top and lower half.

CHAIRMAN JENNINGS: That is very interesting on test bars. Do you find any parallel between that and castings?

MR. ROTH: The only experience we have is on a brake drum, which is poured horizontally. That is the only casting we have made to date out of which we have been able to machine a 0.505-in. diameter bar. We ran over 60,000 lb. per sq. in. tensile on that, as shown in paragraph 20.

MEMBER: Is your pouring temperature the greatest factor in your high tensile figure?

MR. ROTH: So far as the pouring temperature goes, even though this iron has carbon of over 3 per cent, unless we pour it hot, one may have quite a few holes in his casting. As I indicated under the section
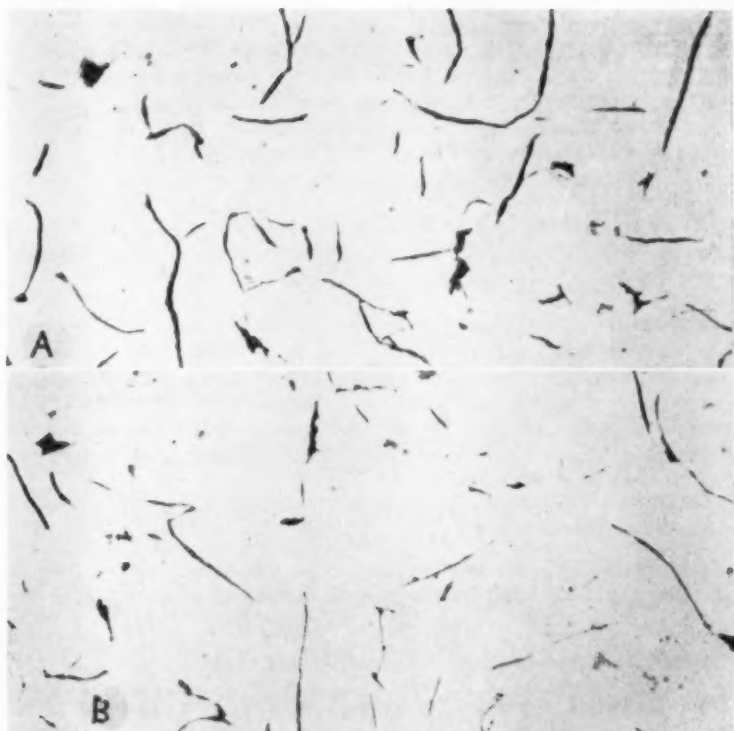
FIG. 9—DISTRIBUTION AND SIZE OF GRAPHITE FLAKES IN HIGH TEST IRONS A AND B. — x250. THE FLAKES IN A LOOK LESS REFINED THAN THEY ARE IN B. THIS IS EXACTLY WHY THE FIRST IS GREATLY SUPERIOR. EACH OF ITS FLAKES IS THICKER, THEREFORE, THERE WOULD BE LESS FLAKES AND LESS SECTIONAL AREA DAMAGED EVEN IF THE GRAPHITE CONTENTS WERE THE SAME. BUT IN ADDITION, SAMPLE B CONTAINS MORE GRAPHITE. SO ITS INFERIORITY DEPENDS UPON: LESS ADVANTAGEOUS SHAPE OF GRAPHITE FLAKES, LARGER AMOUNT OF GRAPHITE PRESENT AND LESSER AMOUNT OF COMBINED CARBON. HOWEVER, ALL OTHER THINGS BEING EQUALIZED, THIS LESSER AMOUNT OF CARBIDE WOULD PRODUCE A DIFFERENCE OF 4.5 PER CENT ONLY IN ITS STRENGTH. AS IT WAS THE STRENGTH DIFFERENCE AMOUNTED TO OVER 25 PER CENT.

on *Pouring Temperatures*, if the temperature is allowed to drop to 2475°F., the tensile strength will drop. For instance, on those little 3-lb. gears, if we attempted to pour them from a 1600-lb. ladle at 2475°F., I venture to say we would have had 100 per cent scrap. We stop pouring them at 2550°F. It is a waste of money to try to pour small molds under that temperature. Our brake drums are poured at 2700°F. right on the conveyor from the cupola.

MEMBER: Is there any maximum carbon content you have found as the limit to give you 60,000 lb. per sq. in. tensile strength?

MR. ROTH: It will be noted that on heat 1027, which ran 3.36

per cent carbon we had 56,760 lb. per sq. in. tensile strength. We feel that the maximum carbon allowable to obtain 60,000 lb. per sq. in. is about 3.25 per cent. I might mention that we start off the cupola with 4,000 cu. ft. of air per min. and keep it at that all through our high strength heat. The highest number of charges we have run in a row is five. We do not size that coke. The average size of coke is about six to eight inches; fairly large size coke for a 48-in. stack.

MEMBER: What type of molding is employed on these castings, especially small castings, and what is your limit on green sand molding? Do you use green sand molding or dry sand molding?

MR. ROTH: All the small gears are made in green sand squeezer molds, and the large valve shown in Fig. 5, a refrigerator cylinder, is a skin-dried mold. Practically all the larger molds are skin dried. On our squeezer molds, we do not observe any large shrinkage or find necessity for risers like they do, say for steel or malleable. It is quite close to gray iron so far as shrinkage characteristics go.

CHAIRMAN JENNINGS: What is your experience in the contraction of this metal for patterns?

MR. ROTH: We use regular gray iron shrinkage. One-eighth in. on ordinary castings and on the larger castings I think we use one-tenth in.

MEMBER: What is the air pressure in the cupola?

MR. ROTH: The pressure is about 10 oz. at the start of the heat; 4,000 cu. ft. per min.

MEMBER: Is that volume constant, day in and day out, or do you put your air in according to the outside temperature, relative humidity and barometric pressure?

MR. ROTH: We have an automatic control that compensates for that. We set the gauge at 4,000 cu. ft. per min. and let it go.

MEMBER: In the first sentence under *Conclusion*, Mr. Roth states: "This material may be substituted for steel castings and forgings due to its much greater wear resistance and good machinability." I just wonder if it might be playing safe to add, "where ductility is not of primary importance?" Because we have tried it as a substitute for pearlitic malleable types of castings, for steel castings in certain applications and it has not been successful, because the shock resistance and ductility required were not met by that type of casting and certainly would not be met by any of our gray irons. I think we should recognize that because it might cause some mis-applications and give the material a black eye.

MEMBER: I understood Mr. Roth to say they had to stop pouring the small gears at 2550°F. What were the nature of the defects when poured after that?

SECTIONAL VIEW
OF SPECIMEN AND HOLDER

SPECIMEN

Setscrew shown
rotated 90° from
actual position
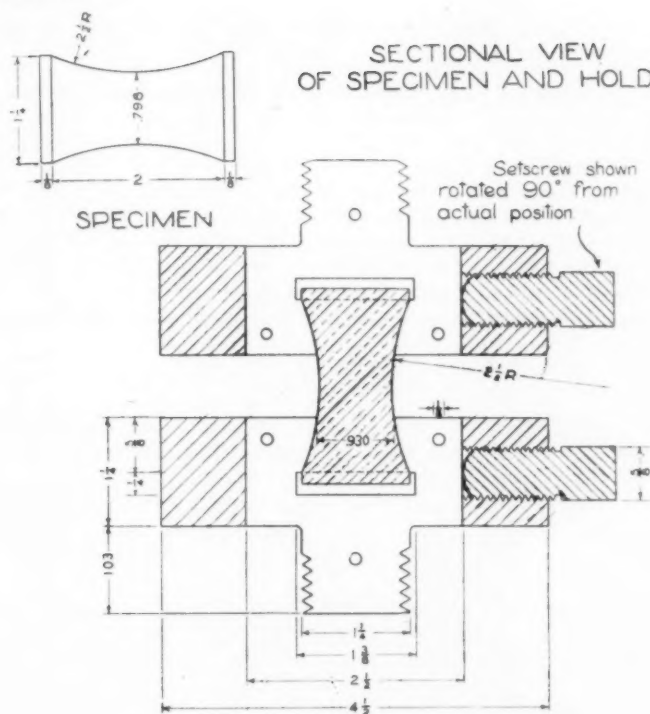
FIG. 10—SECTIONAL VIEW OF SPECIMEN AND HOLDER.

MR. ROTH: Mostly mis-runs. When you get a mis-run casting of 3-lb., made of this material, it is entirely possible the Brinell is 300, because of the low pouring temperature. The castings were un-machinable, and also mis-run. You have to handle the iron pretty fast for small castings.

MEMBER: Mr. Roth do you find that, on this high strength iron, the tensile bars do not break where machined?

MR. ROTH: An inexperienced man on the tensile machine will break almost every one in the threads. The bar has to be quite well centered before the load is put on it or the piece will break in the threads. Also, the machinist, who is making the specimens, should be careful not to get a sharp corner in the bottom of his thread or it will invariably break in the threads.

MEMBER: We find that same experience in our experimental work. I believe we should take some steps to arrange the design of that machined specimen because about the time one gets a nice batch of heat treated machined specimens ready to break he has to discard the results because every one breaks in the thread.

MR. ROTH: Mr. Vanick has developed a bar for heat-treated speci-
mens that seems to give quite good results.

J. S. VANICK:[2] I would like to ask Dr. Eash to discuss this bar.

J. T. EASH:[3] The specimen and holder we use for testing hard
unmachinable irons are best described by the sketch of Fig. 10 and
photograph of Fig. 11. As can be seen, the longitudinal section of the
specimen is cut to a continuous radius and is held by a split holder
having an internal bearing surface machined to the same radius as the
test piece. The split holder has three centering pins and is clamped
together by the ring and set screw and the threaded ends are then
screwed into ball seated supports in the heads of the tensile machine.

MEMBER: Mr. Roth do you find any difference in tensile strength
when you vary the amount of silicon addition?

MR. ROTH: We are attempting to put a 60,000 lb. per sq. in. tensile
strength iron in small castings and in large castings, and we vary the
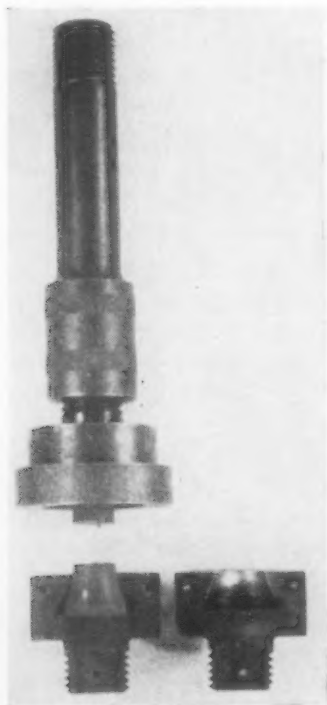
FIG. 11—VIEW OF SPECIMEN HOLDER.

[2] Metallurgist, International Nickel Co., New York City.
[3] Research Metallurgist, International Nickel Co., Bayonne, N. J.

silicon content to get machinability. We believe, although we are not sure, that the tensile strength is fairly uniform in the large and smaller casting because of that silicon addition. We are making that assumption but we do not know that definitely, and that would be quite a research project for a jobbing foundry to dig out.

A. E. HAGEBOECK:[4] I would like to ask Dr. Eash to comment on that special bar. Is it comparable with the 0.8-in. diameter bar when machined with threads, and what size can you use it in?

DR. EASH: The test bar has a minimum diameter in the reduced section of 0.798-in. and has a contour identical to the test section of the bar we use for threaded specimens. We prefer to use a bar having a continuous radius section since it is easier to machine and is less sensitive to bending stresses which may be present than a bar with a parallel section. It is very important that the test bar and holder be machined to the same radius and the specified bar diameter be maintained, otherwise the centers of curvature will differ and the specimen will not bear uniformly on the curved holder and premature fracture may occur. Given the care this kind of a test requires, the apparatus works quite satisfactorily.

MEMBER: Has the author made any experiments showing whether or not the tensile strength gradually decreased as he lowered the pouring temperature of the test bar? In other words, he stated this bar was poured at over 2600°F. He did pour a bar at 2475°F. on which he got below 50,000 lb. per sq. in. tensile strength. Did he make any tests showing the gradual decrease in strength as the temperature decreased? And I would like to know, too, whether or not this low strength was due to physical defects, and why?

MR. ROTH: No, that low strength bar was a good, sound bar. We have not made any tests on the decrease in the pouring temperature. The reason for that, as I think you fellows who run a jobbing foundry can appreciate, is that it is quite a project of itself to make all these analyses and physical tests that we have made to date. It really is beyond the scope of our setup right now to make tests of the type you suggest there.

MR. VANICK: As a matter of supporting Mr. Roth in calling this a 60,000 lb. per sq. in. tensile strength iron as he described it in the title to the paper, I believe he more correctly describes it than calling it a 66,000 lb. per sq. in. iron, as Mr. Corson proposes, because if you are working to specifications for such iron you will need a margin of at least 10 per cent or perhaps 10,000 lb. per sq. in. to deliver an iron safely to a 60,000 lb. per sq. in. specification.

There is one other point that occurs to me in connection with much of this discussion on heat treatment. That is we have found consistently

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[4] President, Frank Foundries Corp., Moline, Ill.

that an iron possessing these strengths "as cast" is a better product than an iron that develops them heat treated. That comment has some bearing on Mr. Corson's discussion in connection with the use of alloys, because when you use alloys, you are in effect heat treating that iron in the mold during its solidification. The function of alloys is to introduce impediments to the cooling rate comparable to what you would get if you tried to quench the castings. The alloying achieves results with a great deal more security so far as obtaining a good casting is concerned, than is possible by quenching and tempering.

The last point I have in mind is one that Mr. Roth mentions, namely, that it is a striking fact to find that an iron like this is in steady commercial production. With some refinement in practice, he should be able, with almost no change in the specification, to push its strength up over 70,000 lb. per sq. in. and do so consistently.

E. W. BEACH:[5] Mr. Roth has told us that he adds his alloys in various quantities, depending upon the casting which he is pouring. A question is: Do you weigh your molten base metal into the ladle you use for adding your alloy? You are very careful, doubtless, to weigh the alloys that you are adding. Do you find any variation in the matter of the size of the ladle or do you guess the amount of base metal into which you are putting your alloys? In one of our operations at Campbell, Wyant & Cannon, we go so far as to make up the ladle by ramming it on a form to obtain accuracy. In addition to this caution, while the ladle is being filled, it rests on a scale. By this method, we are able to add an accurate weight of alloy to an accurate weight of base metal and maintain a ratio without variation.

MR. ROTH: That is a very good point. We do attempt to keep our 1600-lb. ladles very close to size. The actual weight of metal in the ladle is very close to 1600 lb.

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[5] Engineering Executive, Campbell, Wyant & Cannon Foundry Company, Muskegon, Mich.

Elements of the Petrographic Study of Bonding Clays and of the Clay Substance of Molding Sands

By Ralph E. Grim*, Urbana, Ill.

Abstract

This paper briefly outlines the modern methods for the study of clay materials, the prevailing concept of the composition of clays, and the application of modern clay researches to studies of natural molding sands and bonding clays. An appended bibliography of a selected list of reports giving details and theoretical considerations of points discussed is included.

Introduction

1. It has been known for a long time that molding sands are essentially mixtures of silica sand and clay substance with more or less yellow or red hydrated ferric iron oxide. This fact is recognized in the preparation of synthetic sands by mixing silica sand and bonding clay.

2. Papers[1] have been published in the A.F.A. Transactions describing in detail the characteristics of the silica; shape of grains, grain size distribution, etc. Detailed information on the clay substance has not been obtained and investigations of molding sands state only that the quality of the clay substance varies in different sands without making any attempt to study it in detail. Some reports give chemical analyses of the clay, but it is generally recognized that chemical data alone tell very little about the character of a clay.

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3.   Within the last 10 years a large amount of work has been done on the development of methods for the study of clays and in actually studying them by these new methods. A large number of publications in many scientific journals have reported new and important data on the composition and properties of clay materials. As a consequence of this recent work, the characteristics of the clay substance of a molding sand can now be determined as thoroughly as the characteristics of the silica sand portion.

4.   It is proposed in the present paper to briefly outline the modern methods for the study of clay materials, to state the prevailing concept of the composition of clays, and to point out the application of modern clay researches to studies of natural molding sands and bonding clays. For details and theoretical considerations of any points considered herein, reference should be made to the reports of the work on which this paper is based. The appended bibliography is a selected list of such reports.

CLAY COMPOSITION

5.   If a pure clay[2] could be examined with a microscope magnifying many thousand times, it would be found that it was nothing but an aggregation of flake shaped particles. The actual size of these flakes would vary from several microns[3] to less than 0.1 micron in diameter. A working picture of the makeup of clays may be had if one starts with large flakes of mica and then reduces the size of the flakes until each flake is about one micron in size. A mass composed of such flakes approximates the makeup of a clay. If the flakes composing clays are analyzed, it is found that they are composed of atoms of aluminum, silicon, oxygen, and hydrogen. Potassium, magnesium, and/or iron would be found in the flakes of some clays.

6.   The atoms have a definite arrangement in the flakes; e.g., the silicon atoms have fixed positions with respect to the oxygen atoms, the aluminum atoms have definite positions with respect to the oxygen atoms, and so on for the other elements. Substances composed of atoms arranged in a definite pattern are crystalline, and hence the flakes which compose clays are crystalline. The flakes are minute fragments of crystals.

[2]The discussion of clay composition holds for almost all clays. There may be, however, a few relatively unimportant clay materials which have a composition slightly different from that presented.

[3]One micron is one thousandth of a millimeter (0.001 mm.) or about one twenty-five thousandth of an inch (0.00004 in.).

7. That fraction of a clay composed of particles smaller than a given size (±1 micron) is the so-called colloid fraction. The colloidal material in clay is made up of crystalline clay mineral flakes, and it is not an amorphous heterogeneous mixture of silica, alumina, etc.

8. There are several important kinds of flakes which make up clays. All the different kinds of flakes are composed of about the same atoms, but for each kind of flake there is a distinctive and different arrangement of the atoms. From the viewpoint of mineralogy, the different kinds of flakes are different mineral species and warrant different mineral names. These minerals, which are the essential constituents of clays, are called clay minerals. Extensive analysis of clays has shown that there are only three important clay minerals, and that almost all clays are composed essentially of extremely minute flake-shaped particles of one or more of these three minerals (Table 1). In addition to the clay minerals, minor amounts of quartz, organic material, limonite, and other minerals, are also found in many clays. Some examples of the composition of clay materials are as follows: Bentonites are made up of extremely minute flakes of montmorillonite, shales are composed usually of particles of illite frequently with quartz and other minor constituents, fireclays are usually mixtures of flakes of kaolinite and illite, and kaolins and china clays are made up essentially of particles of kaolinite.

Table 1

IMPORTANT CLAY MINERALS

Name	*Chemical Composition*
Kaolinite	$(OH)_8Al_4Si_4O_{10}$
Illite	$(OH)_4K_y (Al_4 \cdot Fe_4 \cdot Mg_4 \cdot Mg_6) (Si_{8-y} \cdot Al_y) O_{20}$
Montmorillonite	$(OH)_4Al_4Si_8O_{20} \cdot XH_2O$

9. Since the atoms are arranged differently in the three important species of clay minerals, it follows that their characteristics, and the physical properties of the clay which they make up will be different; e.g., the characteristics of kaolinite will be unlike those of montmorillonite and the physical properties of a clay composed of kaolinite will be different from those of a clay composed of montmorillonite.

CLAY MINERAL PROPERTIES

10. In the following discussion some of the characteristics of the three important clay minerals which are related to the properties of natural molding sands and bonding clays will be considered.

11. The montmorillonite clay minerals usually occur in particles less than 1 to 0.1 micron in diameter, or in larger particles which are easily reduced to this size when the clay is worked with water. Kaolinite occurs in particles which are rarely smaller than 1 micron and which are not easily broken down by working in water. Most illite occurs in particles about the same size as kaolinite, but there are some clays in which the illite flakes are much smaller. It follows, therefore, that if a clay composed of montmorillonite is compared with one composed of kaolinite, the montmorillonite clay will be made up of smaller flakes than the kaolinite clay. As a consequence, a given amount of montmorillonite clay will contain a larger number of flakes, and a larger total flake surface than will a kaolinite clay As many of the properties of clays are closely related to the size of their component particles, it follows that this difference between montmorillonite and kaolinite would cause clays composed of montmorillonite to have different properties than those composed of kaolinite.

12. All the clay minerals have the power to adsorb certain ions. Thus, if a solution containing lime is passed through a clay some of the lime will be taken out of solution by the clay unless the clay already has all the lime it can adsorb or the lime solution is too dilute. The adsorbed ions are exchangeable, e.g., if a clay carrying lime is treated with a potash solution, some of the adsorbed lime will be replaced by potassium ions. Hydrogen, sodium, potassium, calcium, and magnesium are the common exchangeable ions held by clays. Montmorillonite has about ten times as much capacity as kaolinite to hold adsorbed ions. The capacity of illite varies; some illite has the capacity of kaolinite, whereas other illite has several times this capacity. The difference in the adsorptive capacity of clay minerals is illustrated by their dye adsorption; a montmorillonite clay will adsorb much more dye than a kaolinite clay.

13. It is known in a general way that the physical properties of clays vary with the ion which the clay carries. An example will illustrate the point; if the green and dry compression strengths of two montmorillonite clays are compared, one of which carries hy-

drogen and the other sodium as the exchangeable ion, it will be found that the hydrogen clay has higher green strength than the sodium clay, and that the hydrogen clay has lower dry strength than the sodium clay. The exact variation of bonding properties caused by various exchangeable ions is a promising field of future research which remains to be worked out.

14.   The clay minerals differ from each other in their refractoriness and in their dehydration characteristics. Kaolinite fuses at a much higher temperature than either montmorillonite or illite. Kaolinite loses all of its water when it is heated to about 900°F., and after subjection to this temperature does not again regain its moisture or its physical properties when cooled to ordinary temperatures. Montmorillonite may be heated to about 1025°F. before its moisture is permanently removed and its physical properties are destroyed. The dehydration characteristics of illite are not well known. The above temperatures are equilibrium temperatures. Montmorillonite, for example, must be held at 1025°F. for a considerable period of time before it is completely changed. When montmorillonite is heated to 1025°F. and immediately cooled, only a small amount of it is irreversibly dehydrated.

15.   It is clear from the foregoing considerations that clays composed of different clay minerals must have different properties. A large amount of work must be done before the relation between the various clay minerals and bonding properties are well understood, but some information on this subject is available. It is known, for example, that montmorillonite clays have higher compression strengths than kaolinite clays, and that some illite clays are weak, whereas others have high strength. Thus, a mixture of 95 per cent sand and 5 per cent clay composed of montmorillonite will have greater green and dry strengths than a mixture of 95 per cent sand and 5 per cent kaolinite clay at their optimum moistures. The properties of bonding clays depend, therefore, on the clay minerals of which they are composed. Also, as brought out before, the properties will vary depending on the exchangeable ions which they contain.

16.   Similarly, it is clear that two natural molding sands with the same fineness characteristics, and the same amount of clay will not necessarily have the same strength. In fact the natural sands can *not* have the same strength unless their clay is made up of the same clay mineral carrying the same exchangeable base. It

is obvious, then, that the properties of two sands cannot well be compared without information on the character of their clay mineral content.

DETERMINATION OF MINERAL COMPOSITION

17. It is easy to study the characteristics of the sand grains and of the coarse silt in molding sands with the microscope. Clays generally or the clay substance of molding sands cannot be studied so easily because they are composed of particles which are so small that they cannot readily be seen with the microscope even using very high magnification, much less identified and studied. These very small particles are mostly the clay mineral flakes just mentioned, and only lately has it been possible to devise techniques for their adequate study. In the following paragraphs these techniques are reviewed briefly.

X-ray Method

18. When a beam of x-rays is passed through a crystalline substance, the beam is reflected and refracted from the planes of atoms which make up the crystal. The x-rays emerge from the crystal as a series of beams which can be recorded on a photographic film as a series of lines (Fig. 1) or dots depending on the details of the procedure followed and the character of the material. The position, intensity, and number of beams emerging from any crys-
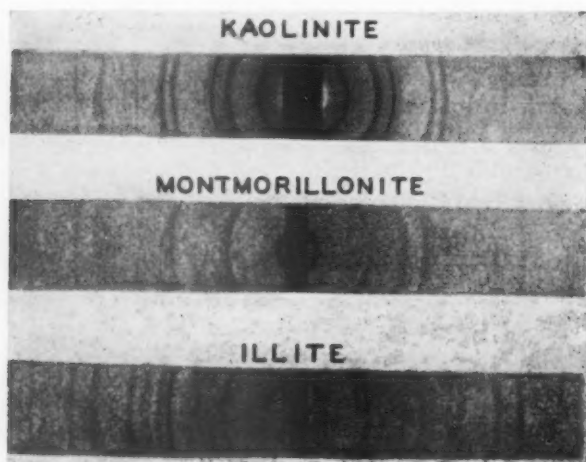
FIG. 1—X-RAY DIFFRACTION PATTERNS. (AFTER W. NOLL, BER. DEUT. KERAM. GES. 19. P. 181, 1398.)

talline substance depend on the character of its atoms and their arrangement in the substance. Thus, it follows that if two crystalline substances with different atomic structures are placed in front of x-ray beams and the emerging beams are recorded on photographic films, the pattern of the lines on the films will be different.

19.   The clay minerals have different atomic structures and, therefore, yield different x-ray patterns. Thus, if a beam of x-rays is sent through a clay sample and the emerging beams recorded, it is possible to determine from the recorded beams the minerals which make up the clay, regardless of the fact that the particles composing the clay are extremely small. The identification of the minerals is made by comparing the pattern from the clay with patterns of known pure mineral material.

20.   One of the greatest difficulties in the identification of the constituents of clays has been to obtain pure samples of many of the minerals found in clay for determining standard analytical data. Thus, it is difficult to obtain pure illite for the study of its x-ray, optical, chemical, and other properties which can be used as a basis of comparison and hence for the identification of illite in clays generally.

21.   It is frequently possible to work out the exact arrangement of the atoms within a crystal from the pattern of the emerging beams of x-rays. In recent years a large body of data has become available on the arrangement of the atoms within the various clay minerals. This work is providing, perhaps for the first time, a fundamental, basic explanation of the physical properties of clays.

Microscopic Method

22.   One difference between crystalline and noncrystalline substances is that in crystals the velocity of light traveling through them depends on the direction of the path of light. In a flake of mica for example, light passing through the flake at right angles to the flake surface has a different velocity than light passing through parallel to the flake. Another character of crystalline material is that light passing through it is polarized, i.e., broken up into light vibrating in only one plane. As a result of these phenomena crystalline substances have certain optical properties. The optical properties of crystals are dependent on their atomic structure and, therefore, materials with different crystal structures, such as the clay minerals, have different optical properties. The

petrographic microscope is constructed so that optical properties can be measured and, as a consequence, minerals can be identified. Satisfactory determinations, however, can only be made on individual particles coarser than about 1 micron, which is larger than many of the clay mineral particles in clays. This limitation to the application of petrographic microscopic technique in the study of clays has been overcome by taking advantage of the flake shape of the clay mineral particles. Aggregates of clay minerals can be prepared in such a way that the flakes rest on top of each other in the same relative crystallographic position. The optical properties of the aggregates can be measured as if they were large individual crystals. In this way the component particles can be identified even though they are too small to be seen individually. The aggregates are prepared by carefully drying suspensions of the clay.

Dehydration Method

23. The clay minerals contain different amounts of water, and they lose their water at different temperatures when heated
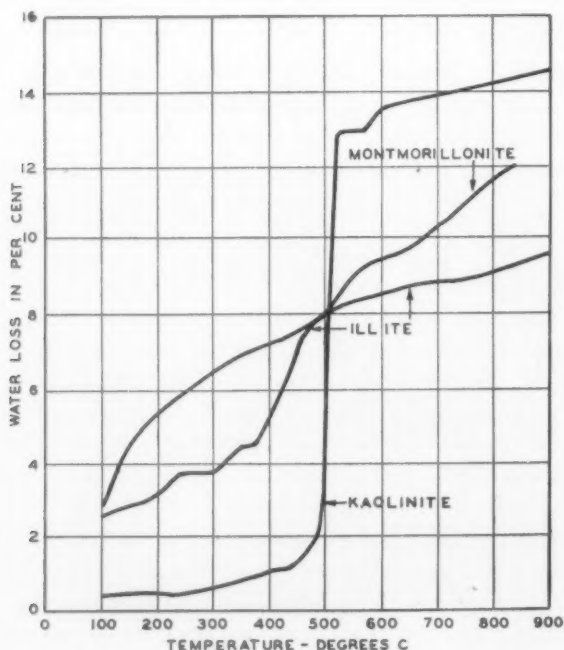
Fig. 2—Dehydration Curves

(Fig. 2). Thus, it would seem possible to determine which clay minerals are present in a clay by determining the amount of water present and the loss of water as the clay is heated. The method has been used in clay studies, but it must be used with caution chiefly because the dehydration characteristics of the clay minerals vary with the size of the particles in which they occur. It has been shown, for example, that extremely finely ground mica has somewhat different dehydration properties than the same mica composed of coarser particles.

Chemical Method

24. Past studies of clay materials have frequently included chemical analyses. In general, chemical analyses alone do not permit an identification of the mineral components of clay substances. Such determinations give values for the amount of silica, alumina, etc., in the substance but do not indicate in what minerals they are present. Therefore, the chemical data do not give information on the units making up the clay which largely determine its properties, i.e., the clay minerals. Along with x-ray and optical analyses, chemical data are helpful; alone they have little value.

APPLICATION OF PRESENT METHODS

25. The study of clay materials has shown that they are frequently composed of mixtures of clay minerals. Clay minerals occurring in mixtures are particularly difficult to study and identify because, although the optical and x-ray properties of the clay minerals on which identification is based are different, the differences are not great and frequently the analytical data for mixtures cannot be interpreted readily. For example, x-ray and optical analytical data for a clay composed of a large proportion of one clay mineral, and a minor amount of another clay mineral, may not positively indicate the presence of the minor component. To overcome this difficulty, a fractionation procedure has been developed which literally takes the clay apart into fractions of its component minerals. The object is to isolate the clay minerals in fractions of sufficient purity so that they can be identified positively.

26. The general procedure is as follows: The material is disaggregated and placed in suspension in water, using ammonia as the dispersing agent. The suspension is allowed to stand until the material coarser than 2 microns has settled out. The suspen-

sion carrying the —2 micron particles then is removed and saved, and the settled material again is placed in suspension and allowed to stand until particles coarser than 2 microns have settled. This process is repeated until the material coarser than 2 microns has been freed of particles smaller than this size, i.e., the sample has been split into a fraction carrying +2 micron particles and a suspension carrying finer particles. The particles in the coarse fraction can be identified and studied individually by means of the petrographic microscope.

27. Oriented aggregates are prepared of the material in the suspension and they are studied with the petrographic microscope. If the finest fraction of the clay is composed of only one clay mineral, it can be studied adequately by x-ray and optical analyses of the entire —2 micron grade size. If the finest grade size is a mixture of clay minerals, it may be necessary to fractionate the suspension by sedimentation (e.g., pipette analysis) or by super-centrifuge processes. By running the suspension through a super-centrifuge, it is possible to separate the particles of the suspension into size fractions. Frequently, fractions containing particles 2 to 1 microns, 1 to 0.1 microns, and —0.1 microns are obtained. Because the clay minerals tend to break down into different sizes, a concentration of clay minerals will be effected by such a fractionation. For example, if the suspension contained kaolinite and montmorillonite, the kaolinite would tend to be concentrated in the +1 micron fraction and the montmorillonite would be concentrated in the —1 micron fractions. Fractions of relatively pure clay minerals would be obtained which would permit accurate identification of the constituents of the clay.

28. Thus by taking a clay material apart a complete picture of its makeup can be obtained. Also the technique gives some information on the size distribution of the minerals making up the material. Such data on the makeup of clays and molding sands are the fundamentals on which studies of the causes of variation in properties must be based. They are the necessary starting point for investigations of why molding sands and bonding clays have the properties they do, and what determines their variations. Until the factors controlling the properties of sands are understood, the sands themselves cannot be controlled with complete satisfaction.

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DISCUSSION

Presiding: H. S. WASHBURN, Plainville Casting Co., Plainville, Conn.

DR. H. RIES[1]: We all realize that this subject is a very deep one and it may seem intensely theoretical, but I believe it brings out one very important point, and that is that as we go farther with the study and the research on molding sands, that we are getting down into finer and finer details. I presume when we first started on molding sands back in 1921, at a time when I think all of us will admit now we did not know anything about them—we thought we did, but we have found out since how little we actually did know—we did not think of these very small details. We knew, of course, that sands had bonds and that these bonds behaved in different ways. Now, we are coming to a point where we are beginning to study these bonds in greater detail. Of course, the study of them requires a considerable expertness, particularly when you have to use these high-powered, complicated microscopes, but, as Dr. Grim has pointed out, we do have these different clay minerals in the bond, and it has been shown that they have different bonding properties, and so that would tend to explain why certain clays might be more efficient as bonds than others.

But there is another interesting point which I think he has brought out—I am not sure whether he mentioned these by name—namely base changes, the possibility of kicking out one ion in a clay and substituting another ion for it, as, for instance, the comparison he drew in the case of this water softening material, the zeolites.

To put it in plain language, we might say we give the clay a dose of salts and, as a result of that, it behaves differently from what it did before.

That opens up an interesting field. It is possible that if a bonding clay does not behave just right, perhaps by treating it with

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some chemical and getting the ions of this chemical to take the place of certain ones which were in the clay, we may improve its properties. Of course, whether we do it or not may be influenced somewhat by the expense which might be incurred by doing so, but I think it is something that will be worth trying in the future.

MEMBER: In the very descriptive information as to the constitution of these various layers, Mr. Grim pointed out that in certain clays the structure shows a contact point of, in one place OH and the other point, O. Does he by these terms indicate that there is actually atomic OH or atomic O? That is, is this contact point based on a chemical reaction?

DR. GRIM: The OH and the O are not in contact. They are parts of different units that tend to make up the whole lattice structure. The theory of the thing is that because you have the OH in the top layer of one kaolinite unit and O in the bottom layer of the next unit, there is a tendency to hold the units in a relatively fixed position which is more secure than you would have if OH and O were in adjacent layers of two units (e.g. montmorillonite).

MEMBER: That supposedly is based on the affinity of those elements for each other?

DR. GRIM: Yes, that is the basis for it.

MEMBER: Dr. Grim could you show by a molecular diagram what happens when the clay substance loses its water. In other words, dehydration.

DR. GRIM: That depends on what sort of clay you are talking about. In the case of montmorillonite, the lattice structure seems to be retained in all of its attributes up to about 550°C. That is about 1025°F. There may be a considerable amount of water present in montmorillonite between the structural units but that is lost at relatively low temperatures, perhaps of the order of magnitude of 220 or 250°F. Above 550°C. the whole lattice tends to break down and different constituents are formed before eventual fusion. Exactly what the mineralogical changes are that take place when montmorillonite and illite break down, are not known, but it is quite well known for kaolinite because the ceramists have worked it out in their study of China clay. There is a change to cristobalite, which is a high temperature form of quartz, and mullite, which is aluminum silicate. As the temperature is raised above the temperature where all the water is lost, mullite and cristobalite form eventually and then later fusion takes place. To be perfectly correct, there is some dispute among ceramists as to the exact sequence of changes that take place within that range when all the water is gone and before the new crystalline material develops. It is difficult to get any positive evidence on which to identify the material. X-ray pictures provide patterns that are very difficult to interpret and you can not see much under the microscope.

MEMBER: Dr. Grim showed the difference between the adjacent layers of kaolinite as differing from montmorillonite and their apparent attraction for each other. What would be the case there in the instance of the illite as regards the adjacent oxygen atoms?

DR. GRIM: Illite differs from montmorillonite in that some of the silicon atoms are replaced by aluminum atoms in the silica tetrahedral sheet. In the lattice structure, silicon carries four charges and aluminum carries three. Every time a silicon is replaced by an aluminum, there is one excess charge in the lattice and that excess charge is usually compensated by an atom of potash that occurs on top of the silica sheet. The potash ions in between the silica sheets act as sort of a bridge that binds them together, so that they do not swell and come apart easily.

Some Tests on the Effectiveness of Water Blast Under High Pressure for Cleaning Castings

By Ronald Webster,* Chicago, Ill.

Abstract

The author discusses casting cleaning by means of water blasting. Tests are outlined which cover the specific effect of water at high velocity against steel, as compared with the effect of water at the same and at lower velocities when mixed with abrasive. Photographs and charts of the results of the tests are included.

Introduction

1. A principle of hydraulics states that water at high velocities will carry a very large amount of material with it and that water at zero velocity will drop all that material. This is essentially what is done in the hydraulic cleaning of castings and is more particularly so in the wet sand blast method. Water has a carrying power in weight and size of material which increases with the sixth power of the velocity. Therefore, at very high velocities, a stream of water will carry very large amounts of material and will impart velocity to this material. Water alone, without solids, will wash away relatively soft material, and if given time, will wear away hard material. When solids are added to high velocity water, this erosive action increases with startling rapidity. Tests, outlined in this paper, cover the specific effect of water at high velocity against steel, as compared with the effect of water when mixed with abrasive at the same or lower velocities. Tests are shown in detail and certain conclusions may be drawn from them.

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2.   The foundry has tried to use, and in some instances has used, water for the removal of cores for a period of 25 years. The general approach has been borrowed from the hydraulic mining industry where a relatively large body of water is thrown with considerable pressure against a bank. The water is used to break out and sluice down the material for handling. It would be possible, on large castings with soft cores, to clean them with a fire hose. To be rapid or effective, a relatively large amount of water would have to be thrown at a pressure of say 300 or 400 lb. per sq. in. The nozzle could not be held by a team of several men, and therefore, would have to be mounted on a support. This kind of device is familiar. It has been used successfully where it could be applied.

3.   Another approach has been made to this problem which until recent years was unsuccessful. The idea and effect of entraining abrasive in a water stream is old and has been used successfully before. The difficulty has laid in the fact that the action was so abrasive that it wore out the equipment which produced it. This problem has been solved by limiting the abrasive action to one confined and easily replaceable part.

4.   It is the effect, not the means, with which we are at present concerned. After the outline of this paper first was prepared, certain other tests were made. These tests show, to some degree, the effect of the addition of abrasives on renewal of material softer than steel, such as core bodies. The tests were conducted in answer to the perpetual question that if sand and water at 1,200 lb. per sq. in. pressure produces this result, "Would not water alone produce substantially the same thing without all this complication?" To answer this question, sections of steel pipe were capped at one end and filled with a weak mixture of cement and sand. The mixture ratio was 7 to 1. This is of no significance except to give a condition which can be reproduced at a later time. This mixture of cement was allowed to set for a period of two weeks. Two, minute determinations were made with water alone at 1,200 lb. per sq. in. pressure. Then with the same amount of water plus sand, another test was run at the same pressure. About ten times as much material was removed in the same period from these pipe sections with sand and water as with water alone.

5.   Another interesting feature of the use of high velocity concerns itself with a totally different subject. A large proportion

of a very fine material, if tossed on the surface of a bucket of water, will float. The specific gravity of the material may be two or three times as great as water. It is held up by surface tension. This surface tension is one of the deceptive features about using water in the removal of material, particularly dust.

6.   It is interesting to note that a velocity of 12,000 ft. per min. or greater is necessary in the Greenburg Impinger, used for obtaining dust samples. A lesser velocity will not wet out the fine particles. A variety of tests, suggested by this fact, have been conducted to determine the effect of high velocity water with or without sand for the removal of dust from the air.

7.   These tests determined that high velocity water containing inundated sand does remove dust from the air, a point of great importance to the foundry industry. Air in the cleaning room is cleaned of fine dust. If foundry air is admitted to the cleaning room, this air also is cleaned. Under conditions where no added air containing dust is admitted to the blasting room, a condition will arise during operation where a maximum amount of fines are in suspension in the air, the highest of which by count is 1,000,000 particles per cu. ft., a figure much below what is considered clean air for a foundry. It is interesting to note, moreover, that this dust so thoroughly wets out and is encapsulated in water that it drops so quickly and completely that no measureable amount of dust remains in the room. This may seem startling. The effect of water at lower velocities is not known because tests have not been made. However, tests conducted at velocities previously mentioned are great enough to wet out micronic fines.

ABRASIVE EFFECTIVENESS TESTS

8.   The series of tests outlined is an attempt to determine the abrasive effectiveness of a stream of water in which sand is entrained as the abrasive agent.

9.   The conclusions drawn from these tests possibly are not applicable to core removal in any direct way, but will serve as a standard of efficiency of a gun or other sand entraining device. At the time of writing, certain research is in progress that may correlate the determination here made with core removal and penetration. The observations made concern: (a) penetration, (b) area of pattern, and (c) loss of weight.

10.   It was deemed desirable to determine the effects of varia-
tions of: (a) pressure, (b) distance, and (c) water alone at high
pressure without entrained abrasive.   Pressures used were: (a)
800 lb. per sq. in., (b) 1000 lb. per sq. in., and (c) 1200 lb. per
sq. in.   Distances used were: (a) 8-in., (b) 16-in., and (c) 36-in.
from the external orifice.   There was one observation at 66-in.   The
volume of sand used amounted to approximately 60 lb. per min.
Two varieties of sand were used.   Analysis of each is shown in
Table 1.

Table 1

ANALYSIS OF SAND USED IN BLASTING TESTS

Beach Sand*		No. One Torpedo Sand*	
Screen No.	Per Cent on Screen	Screen No.	Per Cent on Screen
6	0.0	6	0.0
10	0.16	10	0.83
20	1.63	20	3.00
30	7.50	30	3.68
40	18.20	40	6.00
70	47.08	70	51.84
100	12.35	100	23.60
150	7.35	150	5.20
200	2.85	200	3.88
270	1.50	270	0.80
Pan	0.80	Pan	0.47
Total	99.42	Total	99.30

* Sold under this name by sellers of building material in Chicago.

11.   Two series of tests were run, series *A* with Beach sand,
and series *B* with Torpedo sand.   Each series of tests was made
with identical pressures and at identical distances; the only dif-
ference was in the abrasive used.

Test Plates

12.   To secure as uniform data as possible, test plates measur-
ing 6 x 6 x $\frac{5}{16}$ in. were cut from a single plate of copper bearing
steel after all scale had been removed.   Since scale hardness varies
in any single plate and since there is a possibility that any two
plates may vary in abrasion resistance, plates were cut from the
single plate referred to above.

Orifice Opening

13.   The initial opening, of the water orifice used, was 0.190 in. A new replacement external jet was used for each test. The only type through which abrasives pass.

Angle of Impact

14.   When the angle of impact was considered, the plate was bolted in such a position that the center of impact impinged at an angle of 45 degrees (Fig. 1).
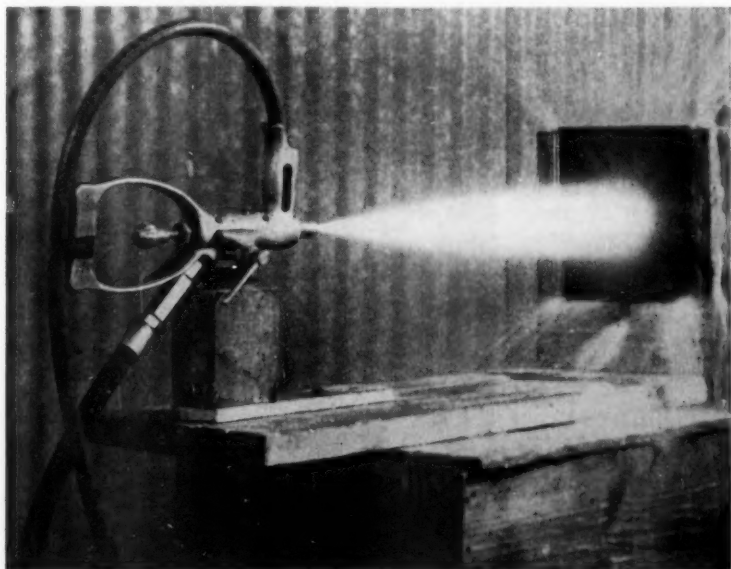
Fig. 1—Test of Erosion and Penetration Using a Standard Blast Gun Without Casing. The Test Plate Is Set at a 45° Angle and at a Distance of 36-in. from Tip of Gun.

Water

15.   The quantity of water involved in these tests is approximately 30 gal. per min. at 1200 lb. per sq. in. pressure. This amount is somewhat less at the decreased pressures. No actual measurement of water was made. However, from observation, there is no reason to believe that the volume used varied between any two test pieces at any given pressure.

16.   Volumetric computations show that the velocity of this sand and water, as it leaves the replaceable jet orifice at 1200 lb. per sq. in. pressure, is in excess of 18,000 ft. per min.

Weight Loss

17.   Figs. 2 to 8 express in grams the loss in weight in each plate over the 8 min. period of each test. It is believed that this loss of weight may have some degree of statistical significance.

Sand

18.   The uncontrolled variable, which could not be measured readily, was the actual amount of sand thrown. (From visual observation there was no interruption in the sand flow. However, a slight stoppage or diminution could not have been detected. The actual weight of metal lost was sufficient to overcome most of the minor variabilities in operation.)

19.   To consider the effectiveness of abrasives used and the pattern formed, it will be noted from the illustrations that with fine sand, there was no noticeable difference in the weight of metal removed at the three distances tested. However, there was a totally different pattern at various distances. This is illustrated in Fig. 3. It is noted that a maximum depth effect is obtained at 8-in. and a greater width effect at 36-in.

36-in. from Gun   16-in. from Gun   8-in. from Gun

FIG. 2—PATTERN PROFILES AND PHOTOGRAPHS OF TEST PLATES 1, 4 AND 7, TESTED UNDER THE FOLLOWING CONDITIONS: HYDRAULIC PRESSURE—1200 LB. PER SQ. IN.; ABRASIVE—FINE BEACH SAND; BLASTED FOR 8 MIN.; WEIGHT LOSS IN GRAMS AT VARYING DISTANCES FROM NOZZLE TO PLATE: 8-IN.—24.88 GRAMS; 16-IN.—26.44 GRAMS; 36-IN.—26.44 GRAMS.

36-in. from Gun   16-in. from Gun   8-in. from Gun

Fig. 3—Pattern Profiles and Photographs of Test Plates 10, 13 and 16, Tested Under the Following Conditions: Hydraulic Pressure—1200 lb. per sq. in.; Abrasive—No. One Torpedo Sand; Blasted for 8 min.; Weight Loss in Grams at Varying Distances from Nozzle to Plate; 8-in.—27.99 grams; 16-in.—31.10 grams; 36-in.—23.33 grams.

36-in. from Gun   16-in. from Gun   8-in. from Gun

Fig. 4—Pattern Profiles and Photographs of Test Plates 2, 5 and 8, Tested Under the Following Conditions: Hydraulic Pressure—1000 lb. per sq. in.; Abrasive—Fine Beach Sand; Blasted for 8 min.; Weight Loss in Grams at Varying Distances from Nozzle to Plate; 8-in.—17.11 grams; 16-in.—21.77 grams; 36-in.—20.22 grams.

36-in. from Gun   16-in. from Gun   8-in. from Gun

FIG. 5—PATTERN PROFILES AND PHOTOGRAPHS OF TEST PLATES 11,
14 AND 17, TESTED UNDER THE FOLLOWING CONDITIONS: HYDRAULIC
PRESSURE—1000 LB. PER SQ. IN.; ABRASIVE—NO. ONE TORPEDO SAND;
BLASTED FOR 8 MIN.; WEIGHT LOSS IN GRAMS AT VARYING DISTANCES
FROM NOZZLE TO PLATE; 8-IN.—23.33 GRAMS; 16-IN.—23.33 GRAMS;
36-IN.—18.66 GRAMS.

36-in. from Gun   16-in. from Gun   8-in. from Gun
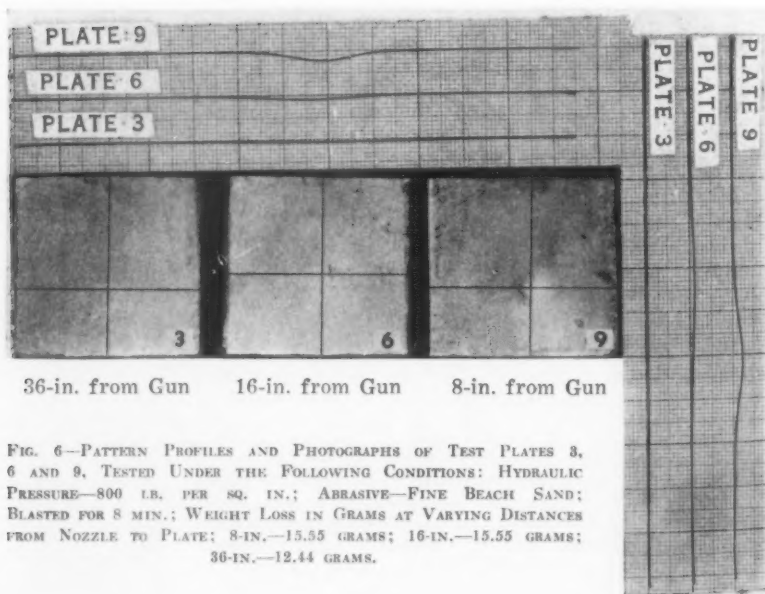
FIG. 6—PATTERN PROFILES AND PHOTOGRAPHS OF TEST PLATES 3,
6 AND 9, TESTED UNDER THE FOLLOWING CONDITIONS: HYDRAULIC
PRESSURE—800 LB. PER SQ. IN.; ABRASIVE—FINE BEACH SAND;
BLASTED FOR 8 MIN.; WEIGHT LOSS IN GRAMS AT VARYING DISTANCES
FROM NOZZLE TO PLATE; 8-IN.—15.55 GRAMS; 16-IN.—15.55 GRAMS;
36-IN.—12.44 GRAMS.

36-in. from Gun   16-in. from Gun   8-in. from Gun
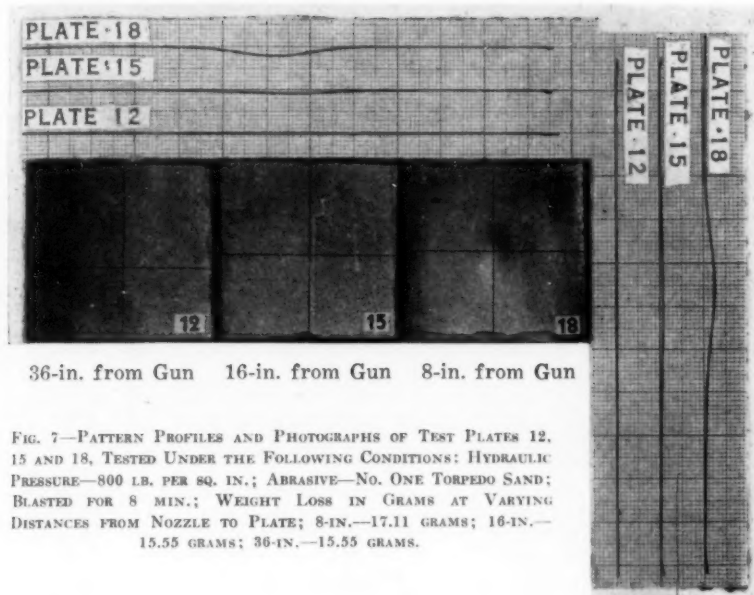
FIG. 7—PATTERN PROFILES AND PHOTOGRAPHS OF TEST PLATES 12, 15 AND 18, TESTED UNDER THE FOLLOWING CONDITIONS: HYDRAULIC PRESSURE—800 LB. PER SQ. IN.; ABRASIVE—NO. ONE TORPEDO SAND; BLASTED FOR 8 MIN.; WEIGHT LOSS IN GRAMS AT VARYING DISTANCES FROM NOZZLE TO PLATE; 8-IN.—17.11 GRAMS; 16-IN.—15.55 GRAMS; 36-IN.—15.55 GRAMS.

8-in. from Gun
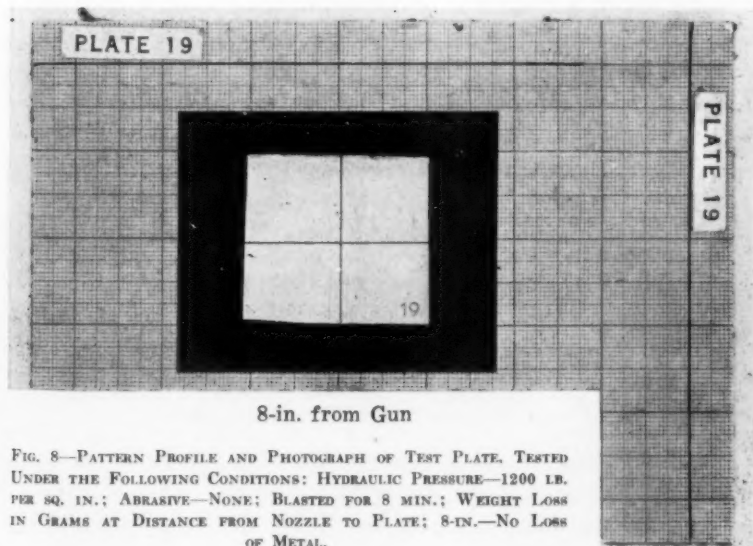
FIG. 8—PATTERN PROFILE AND PHOTOGRAPH OF TEST PLATE, TESTED UNDER THE FOLLOWING CONDITIONS: HYDRAULIC PRESSURE—1200 LB. PER SQ. IN.; ABRASIVE—NONE; BLASTED FOR 8 MIN.; WEIGHT LOSS IN GRAMS AT DISTANCE FROM NOZZLE TO PLATE; 8-IN.—NO LOSS OF METAL.
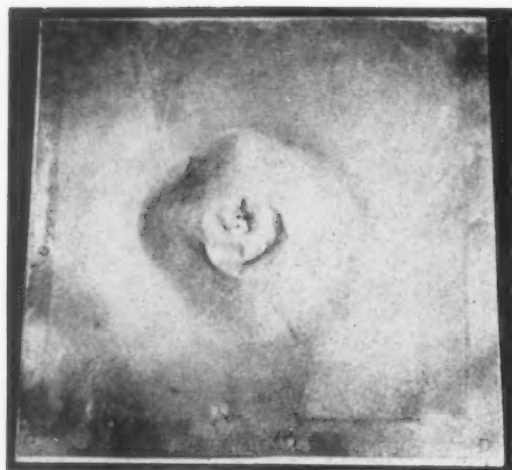
FIG. 9—RESULT OF IMPACT TEST ON A 22 GAGE STEEL SHEET 12x12 IN. BACKED WITH SOLID WOOD. THE ABRASIVE USED WITH THE WATER WAS A NO. ONE TORPEDO SAND WITH A HYDRAULIC PRESSURE OF 1200 LB. PER SQ. IN. THE BLASTING TIME WAS 6 MIN. AT A DISTANCE OF 36-IN.

20. In test series B where the coarser sand was used, there is an apparent increase in the amount of material removed at the 16-in. distance and a decrease at the 36-in. distance. This is probably an erroneous conclusion, because at the other pressures tested with the coarse sand, the difference between 8-in. and 16-in. is insignificant, but at 36-in., there is a consistent drop in effectiveness not apparent with the fine sand. There seems to be little difference between the coarse and fine sand. No tests were made indicating the difference in effect of sharp and round sand when used as an abrasive. No tests were made to indicate any difference between beach and silica sand.

RESULTS OF TEST

21. It was intended that one test should be run at each pressure with high-pressure water alone. The first test was run at 1200 lb. per sq. in. for 8 min. at a distance of 8-in. and showed no measurable change in weight. Therefore, further tests with high pressure water alone were eliminated as not indicative.

22. One observation at 1200 lb. per sq. in. pressure using the fine sand, series A, at a distance of 66-in. and for a period of 8 min. gave a maximum penetration of 0.01562 in. This test indicates the
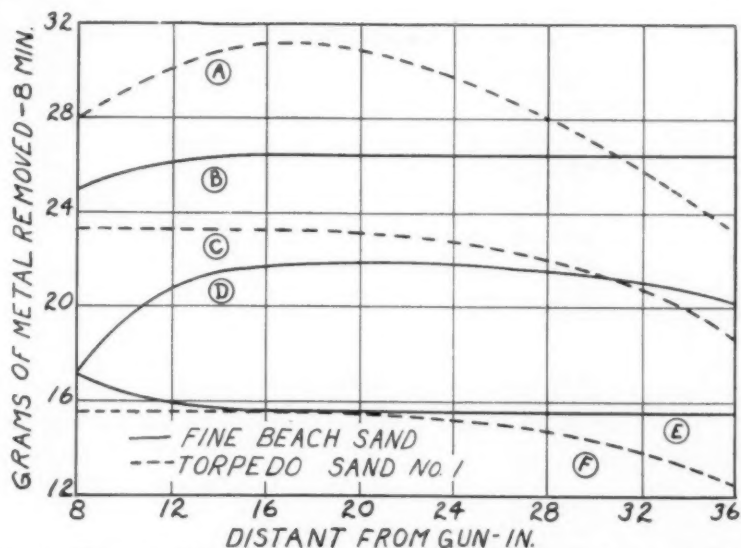
FIG. 10—WEIGHT OF METAL REMOVED IN GRAMS, USING MIXTURE OF WATER AND FINE BEACH SAND AND WATER AND NO. ONE TORPEDO SAND, AT A BLAST PRESSURE OF 1200, 1000 AND 800 LB. PER SQ. IN. FOR THE TIME OF 8 MIN., AT VARIOUS DISTANCES FROM GUN TO THE PLATE.

desirability of further exploration at distances greater than those used in these tests.

23.   Table 2 shows the force of striking, that is, the actual total impact of the sand and water against a scale. A vertical weight scale, graduated in ounces, was used. The gun was directed at a plate on the scale at an angle of 45 degrees and the balance adjusted.

Table 2

WEIGHT OF SAND AND WATER USED AT VARYING PRESSURES
AND DISTANCES

Hydraulic Pressure, lb. per sq. in.	Distance, Inches	Weight of Sand and Water in Pounds
1200	36	31.5
1200	16	28.5
1200	8	26.0
1000	36	22.0
1000	16	25.0
1000	8	23.0
800	36	18.0
800	16	19.5
800	8	19.0

CONCLUSION

24. In conclusion, it may be said:

   (1) That sand entrained in high velocity water has an appreciable abrasive action on metal.

   (2) That the effectiveness of sand and water does not change significantly up to 36 in. However, the stream becomes less concentrated at a distance.

   (3) That water alone, even at 1200 lb. per sq. in. pressure, has no significant effect.

DISCUSSION

Presiding: E. W. BEACH, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Co-Chairman: JAMES THOMPSON, Continental Roll & Steel Foundry Co., East Chicago, Ind.

CHAIRMAN BEACH: What is the actual length of the gun shown in Fig. 1?

MR. WEBSTER: The actual overall length of the gun is about 12 in. With the addition of the stock, it can conveniently be operated by an average size or large size man.

MEMBER: What grain size do you find most effective with your 1200-lb. pressure?

MR. WEBSTER: It depends on what you are trying to do with it. Where the scale is very brittle, like annealing scale on steel castings or like bath tub enamel, one wants as large and heavy a grain as he can get, because the effect in cleaning is one of a shattering blow, for the material attacked is very brittle. On the other hand, with a scale which is tight and not necessarily very thick, a finer sand is just as rapid as a coarse material, and has many advantages. A finer sand does not pit or peen the surface of the metal.

MEMBER: What is the percentage of water by weight of the sand used?

MR. WEBSTER: It is about 3 parts water and 1 part sand, or approximately a 25 per cent concentration as it leaves the gun.

MEMBER: Would there be any greater effect if steel shot abrasive was used?

MR. WEBSTER: That would depend on what one wants to accomplish with the steel shot. In some instances, steel shot would be an advantage (if it could be made to go through such a device), but there are a good many other problems in handling steel shot, especially if it is mixed

with a lot of core sand. It depends upon the result you require. In some instances, on certain types of scale, we have demonstrated that with sand we can clean 20 per cent faster than with a shot-throwing device. Like other equipment of this character, this machine or equipment is not universal in its application.

MEMBER: How do you develop that water pressure?

MR. WEBSTER: We use a triplex pump.

MEMBER: Does the sand injure the pump in time?

MR. WEBSTER: The sand does not go through the pump at all because the water is not recirculated. We use new water for each gun every time. Figuring water at 10 cents a thousand gal., one of these guns will cost about $1.20 a shift to operate, which is comparable with the cost of air.

MEMBER: How does the cost of cleaning castings by this method compare with shot or sand and air?

MR. WEBSTER: In the first place, this device may be considered primarily as replacing not only sand blasting, but the other operations preparatory to blasting. At one plant, the castings are pulled out of the pits with sand adhering to them, and placed in the water blast room where the entire cleaning takes place in one operation. At another plant, the castings are pulled out of the flasks, leaving as much sand as possible on the casting, allowed to cool and then put on a traveling conveyor. The cores are knocked out and the internal parts, where there is usually a great amount of difficulty in cleaning by the ordinary methods, are cleaned easily. Very little attention is paid to the external part of the casting at that foundry, because they all go into the anneal afterward, and then, after the anneal, they are run through a shot blast. Most of the sand comes off in the annealing furnaces so that when they get into the final clean-up, there is substantially no sand to interfere with the action of the shot on annealing scale. In that instance, I think there are two operations and they should be done by two different pieces of equipment.

MEMBER: Has the speaker any figures on the sq. ft. per min. cleaned by this method?

MR. WEBSTER: I have no figures of that character. We have not considered ourselves as directly interested in surface cleaning except where the type of surface required in the finished product is such that this system will give better results than one of a different character.

MEMBER: Mr. Webster, have you had any experience with getting hard oil sand cores out of very thin sections of castings?

MR. WEBSTER: We have. I know that we can remove cement-bound material because I have cleaned up a locomotive crosshead myself. In this case all the inside cores were made with cement as a bond.

MEMBER: Is the gun operated on the injection or ejection principle?

MR. WEBSTER: We get a vacuum of between 27 and 28 in. of mercury at the suction end of the sand line, and pull the sand up. The high-speed jet passes through, what we call, a mixing chamber and the sand goes out with it. I should say it operated on the ejection principle.

MEMBER: What effective lift can you depend upon in a gun of that kind?

MR. WEBSTER: We find that it is more practical to lift the sand even if we lift it only a small distance, because of the danger of plugging. We find that if sand tries to flow by gravity or moves rapidly and there is any kind of stoppage, it does not clear itself. We had to design a rig so that any foundry operator could be taught how to operate it in two hours.

MEMBER: Do you get similar service results from your gun effect on steel as you do on cast iron, or gray iron castings?

MR. WEBSTER: You can get as clean a surface on any kind of casting as you want, if you take the time on it. The actual cleaning effect is a little different, and you can see why. The water is traveling at a very high rate of speed and it removes the minute particles of abrasive that would ordinarily lie in the pores of the metal, so that it is practical to really clean a material and not leave a residuum of abrasive on the surface or in the pockets.

CHAIRMAN BEACH: There is one point which I do not think Mr. Webster has clarified in describing his illustration. I do not believe those here appreciate that the vital point in Mr. Webster's operation is the use of wet sand in place of dry sand and that wet sand is essential to the proper functioning of the gun. It was called to our attention, in Mr. Webster's paper, that a surplus of water on the top of the sand tank was essential to the operation. For the benefit of those here, will Mr. Webster please repeat the detail of the water feed, amplifying it a little in order that we may have a clearer conception of the operation?

MR. WEBSTER: In order to operate the gun in a satisfactory manner all the time, a dry sand feed is not satisfactory. It can be done, but the sand has to be very dry. Consequently it runs, and, of course, trying to keep sand very dry and in a running condition around a wet blasting unit, is not easy. However, the principal value of the water is that we have a head of water over this sand and a feeding device in the bottom of the sand hoppers which admits a regulated flow of sand into the line. It is a matter of controlling orifice sizes, with relation to head, on both sides of the system. That is, one size would not hold for another size of gun, for example. One could very easily make a sand pump out of this type of gun. You could cease to contribute great velocity to the sand and could merely pump large quantities of sand. That would be merely carrying the thing to absurdity. We seem to have arrived at about the maximum effective amount of sand that can be

handled in one of these guns, that is, where the velocity contributed to the sand is about the maximum. It may be possible to add another 10 per cent to efficiency in the course of the next two or three years.

MEMBER: Is my recollection correct that you pump about 60 to 70 lb. of sand per min. with 27 gal. of water through a 0.190-in. diameter orifice? Why not an orifice of 0.200-in. diameter?

MR. WEBSTER: That happens to be about the top gallonage and back pressure that a man can hold. If we went up to 0.210-in. orifice, it would take a very strong man to hold it, but when it is held to 0.190-in., there is no fatigue developed in operation. In this gun, we use about 28 gal. of water per min. at 1200 lb. pressure. The initial orifice is 0.190-in. on what we call our standard gun. That allows us to throw between 60 and 70 lb. of sand per min. at a velocity, in excess, of 18,000 ft. per min.

There is one thing that I did not mention in connection with our cleaning method. In all cleaning operations at the present time, a clean atmosphere has become of vital importance. I am pleased to say that the results of dust studies, which we made a short time ago, are eminently satisfactory. In one plant blasting room, while the device was operating, we obtained a dust count of about 1,000,000 particles per cu. ft. The general foundry air outside the room, prior to this sample, approximated 3,000,000 particles per cu. ft. We then took simultaneous samples at intervals of one hour both inside and outside of the cleaning room. The air in the general foundry outside of the room dropped to 2,000,000 particles per cu. ft., and the air in the open roofed room was 1,000,000 particles per cu. ft.; which makes it quite apparent that the device itself acts as an air cleaner.

MEMBER: Has anybody ever said anything about the humidity set up by the spray of water flying through the air like that?

MR. WEBSTER: The operator is breathing air that has been filtered and dried before being piped to his helmet. In a room, open to the rest of the foundry, the splash boards confine the direct water splash to the inside of the room. There is ordinarily a down draft there, too, because the water is generally cooler than the foundry air. We have never had any complaint about the area outside of the room being humid. The inside of the room gets distinctly humid, especially if the casting being cleaned is pretty warm. In that case, if it becomes practicable, we would have to put in, not a forced ventilation, but some sort of ventilation openings that would allow the steam and fog to escape.

MEMBER: Is the 45° which the chart indicates, the most effective angle for direction of the sand-water stream?

MR. WEBSTER: I believe that one company, 10 or 12 years ago, made some studies as to the effective angle and concluded 45° to be efficient. We have not made sufficient comparative studies in the matter of stream angle to know whether 37½° or 45° would be correct, but

at any rate the stream is most effective when there is no interference through rebound of the sand particles striking the surface of the object being cleaned, whether there is any other action, I do not know.

MEMBER: Is there a rust preventive used in the water?

MR. WEBSTER: We have found that we can use a solution of potassium bichromate (about one pound to 8,000 gal. of water), which will cause the castings to dry bright. There will be a slight discoloration. If the castings are going to be galvanized afterwards, Dr. Speller tells us that the castings should be treated with a weak solution of muriatic acid to remove the bichromate of potassium. In the case of enamelling, I have just heard that a company has been conducting some experiments in that direction and find that the presence of a film of potassium bichromate has no effect at all on the ability to enamel the surface.

The material is not a permanent rust inhibitor; that is, if the castings are left out in the rain or handled continuously, they will rust in the same way as would any other castings under similar conditions. Castings cleaned with this rust preventative in the water will dry without the formation of rust.

MEMBER: In the use of bichromate of potassium, is there any bad effect on the men handling castings treated in this manner, if, for instance, they had scratches or abrasions on their hands?

MR. WEBSTER: The question is whether or not any poisoning or dermatitis of any kind could arise from the use of Potassium bichromate as an inhibitor in case the man was in contact with it. My authority is again Dr. Speller, corrosion expert of the National Tube Co., Lorain, Ohio. He tells me that he has been using a hot rather concentrated solution of potassium bichromate on pipe for 25 years. He states that certain people are allergic to potassium bichromate and must not be employed on the job. However, most people are not affected by it and it causes none of the symptoms that are in any way connected with chromic acid poisoning, which has a very different physiological effect.

Practical Job Evaluation For the Small Foundry

By E. L. ROTH*, MILWAUKEE, WIS.

1. During 1937, employers were faced constantly with demands for flat increases in day rates and piece work rates ranging from 5 to 25 per cent in some cases. In practically all jobbing foundries, there are two classes of workers, (1) those who are paid on an hourly basis such as flask carriers, maintenance men, core carriers, sand mixers, etc. and (2) piece workers such as molders, core-makers, grinders, chippers, etc.

2. Due to a scarcity of labor, the skilled workers in most instances were receiving a fairly uniform wage in different shops, and the minimum wage rate in the majority of shops was practically the same for a given locality. The big group of workers between the top and bottom wage rates, however, were receiving, and still are receiving, widely varying rates of pay for doing practically the same type of work.

3. A demand for a flat increase throughout a small jobbing plant, if granted, could raise the foundrymen's costs way out of line. In many cases a certain number of the laborers had a justifiable complaint because of the haphazard manner in which these rates had been set. Also a flat increase could raise the skilled workers above a fair rate for the type of work being done and could start also a vicious circle of unreasonable wage increases in other foundries in that locality. The not too far fetched result of such a proceeding naturally would result in a decreasing use of castings due to high costs and substitution of stampings, welded structures, etc.

4. The answer to this problem, which in the writer's opinion is not over and has only just begun, is for even the smallest jobbing foundry to evaluate every job in their plant basing it on a fair minimum and a fair maximum. Immediately the small foun-

dryman says "I know what each job is worth and furthermore any of these systems are too complicated," or "We're too small for anything like that," or "We can't hire a personnel manager." (Who makes their O.A.B. reports, unemployment reports, etc?)

5. We believe that the system presented here is understood easily by owner, manager, foreman and workmen and its adoption will save many headaches and produce a minimum of complaints when in the future, due to economic conditions, flat increases or flat decreases become necessary. In periods of depression the foundryman can *make his own* decreases, but unless they are fair and just, he is only building up later exorbitant demands and real trouble for periods of prosperity.

EXPLAINS METHOD

6. We do not claim to be the originators of the job evaluation method described here as it was devised by Merrill R. Lott and published in 1926 by the Ronald Press in the book "Wage Scales and Job Evaluation." We merely present it here to show its practical application to our industry.

7. Obviously, any piece work plan, to be successful, must be based on properly evaluated day rates for a given job, because every time study when completed, must go back to a day rate for setting the final piece work rate. Quite a few papers and articles have been written on this subject but they usually are vague on the exact procedure for arriving at the so-called difficulty points which each job is worth.

8. The first step is to list each job in your plant by departments. For example the classifications we arrived at were as given in Table 1. Since there are probably no two jobbing foundries in this country making exactly the same kind of castings, there would be many variations in this list and the detailed description of the work to be done on each of the above jobs would differ greatly.

9. If the evaluated points are to be determined by a group, consisting of the foreman of the department, a committee of workmen, and the Shop Superintendent, it will be surprising how easy it will be to arrive at satisfactory figures, providing each member of the group has been furnished with a detailed description of the duties and work to be performed in each classification.

10. The job evaluation for each job classification is made by

using the fifteen factors of Table 2 which add up to 100 per cent. A complete breakdown of these factors is given in Table 3. A convenient mimeographed form for tabulating the results obtained by use of the above formula is illustrated in Fig. 1. The tabulation shown is our final job evaluation for the pattern worker required in *our own shop*.

11. A lengthy discussion of the method of applying the formula is unnecessary because it really is self explanatory. The various factors fit in perfectly regardless of the type of job being evaluated. After the evaluation points are obtained and applied to the chosen minimum of 50 cents per hr., and the chosen maximum of 90 cents per hr., as shown in Fig. 2, it is found that in our case 50 points is equivalent to 3 to 4 cents per hour. This means that even big differences of opinion on the original job evaluation

Table 1

CLASSIFICATION OF JOBS BY DEPARTMENTS

A. MOLDING DEPARTMENT
   1. Floor Molder
   2. Machine Molder
   3. Machine Molder Finisher
   4. Bench Molder — Loose
       Patterns
   5. Squeezer Molder
   6. Molders Helpers
   7. Flask Carrier
   8. Facing Mixer
   9. Shakeout and General
       Labor
   10. Flask Carpenter

B. CORE DEPARTMENT
   11. Jacket Makers
   12. Floor Core Makers
   13. Machine Core Makers
   14. Core blower
   15. Assembler
       a. Expert
       b. Good—all dry sand
            jobs
   16. Core Sand Mixer
   17. Sand Delivery Man
   18. Wire Cutter
   19. Core Piler
   20. Core Carrier
   21. Electric Truck Driver

C. CLEANING AND SHIPPING
   DEPARTMENT
   22. Tumbler Men
   23. Chippers & Grinders
   24. Sandblast Room Operator
   25. Sandblast Helper
   26. Finisher—First Class
   27. Finisher — Bench —
       Cylinders
   28. Inspectors
   29. Welder
   30. Truck Driver

D. MELTING DEPARTMENT
   31. Cupola Tender
   32. Cupola Chargers
   33. Cupola Laborer
   34. Ladle Liner
   35. Yard Laborer
   36. Laboratory Assistant

MISCELLANEOUS
   37. Pouring Gang
   38. Maintenance Men
   39. Pattern Maker
   40. Sweeper
   41. Car Unloaders

<u>JOB ANALYSIS SHEET</u>

<u>DESCRIPTION OF WORK</u>: PATTERN MAKER, CUSTOMER
PATTERN CHANGES, MOUNT PATTERNS ADD
GATES, REPAIR & MAINTAIN PROD. PATT'S.

FACTOR NO.	WEIGHT MULTIPLIER			NO. POINTS	.
1.	23 x	10	=	230	
2.	7 x	5	=	35	
3.	5 x	6	=	30	
4.	4 x	1	=	4	
5.	8 x	10	=	80	
6.	5 x	8	=	40	
7.	9 x	8	=	72	
8.	7 x	10	=	70	
9.	6 x	8	=	48	
10.	7 x	6	=	42	
11.	3 x	2	=	6	
12.	7 x	1	=	7	
13.	3 x	4	=	12	
14.	3 x	1	=	3	
15.	3 x	1	=	3	

TOTAL   682   POINTS

FIG. 1—A SAMPLE MIMEOGRAPHED FORM FOR TABULATING FACTORS OF A JOB ANALYSIS.

given in Fig. 1 really mean small differences in the final hourly
evaluated day rate.

12.   The dotted line in Fig. 2 shows what would happen if a
55 cent per hour minimum had been used with the 90 cent
maximum. From Fig. 2, we made up the rate classification table
shown as Table 4 and applied this to the evaluated points for each
job in order to set the rate.

13.   Because the formula is so clear in the breakdown of

Table 2

Factors in Evaluation of Jobs

	Factors	Per Cent
(1)	Time Required to Learn Trade	23
(2)	Time to Adapt to Conditions	7
(3)	Scarcity of Labor	5
(4)	Difficulty in Getting Another Job	4
(5)	Educational Requirements	8
(6)	Prevailing Rate of Pay	5
(7)	Accuracy and Skill Required	9
(8)	Ingenuity	7
(9)	Manufacturing Hazard	6
(10)	Honesty of Effort	7
(11)	Dirtiness of Working Conditions	3
(12)	Health Hazard	7
(13)	Accident Hazard	3
(14)	Physical Effort	3
(15)	Monotony	3
		100
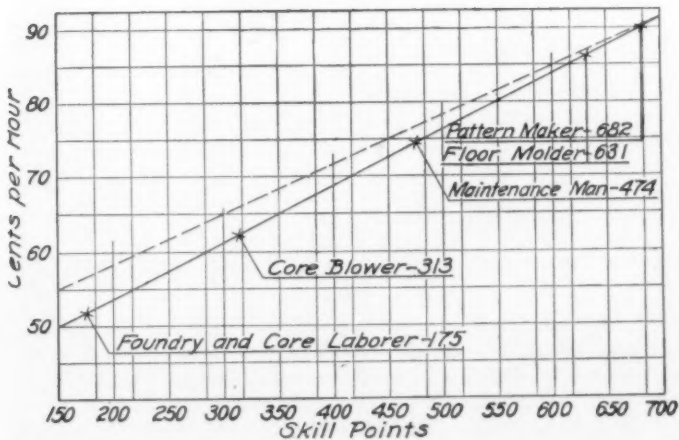
FIG. 2—CHART FOR EVALUATION OF DAY WORK RATES ACCORDING TO SKILL POINTS.

Table 3

BREAKDOWN OF FACTORS OF TABLE 2

FACTOR NO. 1—*Time Required to Learn Trade—Multiply by 23.*

Years or More Experience	Points To Be Allowed
9 to 10	10
8 to 9	9
7 to 8	8
6 to 7	7
5 to 6	6
4 to 5	5
3 to 4	4
2 to 3	3
1 to 2	2
Less than 1	1

FACTOR NO. 2—*Time to Adapt to Conditions—Multiply by 7.*

Years	Points To Be Allowed
3 or more	10
2½ to 3	9
2 to 2½	8
1½ to 2	7
15 to 18 (Months)	6
12 to 15	5
9 to 12	4
6 to 9	3
3 to 6	2
3 or less	1

FACTOR NO. 3—*Scarcity of Labor—Multiply by 5.*

Occupation for Which:	Points To Be Allowed
No Trained Men Are Available	10
There Is a Scarcity of Men	8
It Is Difficult To Get Men	6
Men Are Available	4
Men Can Readily Be Found	2
There Is an Abundant Supply	1

FACTOR NO. 4—*Difficulty in Getting Another Job—Multiply by 4.*

	Points To Be Allowed
Very Special Work—Similar Job Not Available	10
Job Such that Difficult To Find Similar Work	7
Job Such that Similar Work Can Be Found	5
Job Such that Similar Work Can Readily Be Found	3
Job Such that Similar Work Can Easily Be Found	1

Table 3 (continued)

FACTOR No. 5—*Educational Requirements—Multiply by 8.*

Work Requiring:	Points To Be Allowed
High School Education	10
Two Years High School	7
Grade School Education	5
Sixth Grade Education	3
Third Grade Education	1

FACTOR No. 6—*Prevailing Rate of Pay—Multiply by 5.*

Prevailing Rate of Pay Per Hr.	To Be Allowed Points
$1.00	10
0.90 to $1.00	9
0.80 to 0.90	8
0.70 to 0.80	7
0.60 to 0.70	6
0.50 to 0.60	5
0.40 to 0.50	4
0.30 to 0.40	3
0.20 to 0.30	1
Less than .20	

FACTOR No. 7—*Accuracy and Skill Required—Multiply by 9.*

Degree	Points To Be Allowed
Very Skillful (Tool Maker)	10
Skillful (Machine Operator & Pattern Maker)	8
Ordinary Accuracy and Skill	5
Little Accuracy or Skill (Bench Assembler)	3
Practically no Skill	1

FACTOR No. 8—*Ingenuity—Multiply by 7.*

Ingenuity:	Points To Be Allowed
Great Deal Needed	10
Reasonable Amount Needed	7
Average	5
Little Needed	3
None Expected	1

FACTOR No. 9—*Manufacturing Hazard—Multiply by 6.*

Work Where:	Points To Be Allowed
Concentration, Caution and Judgment Are Necessary	10
Error Makes Expensive Loss	8
Error Makes Loss of Parts	6
Error Makes Repairs Necessary	4
Chance of Error Creating Loss Is Low	1

(Only Unintentional Errors Considered)

Table 3 (Continued)

FACTOR NO. 10—*Honesty of Effort—Multiply by 7.*

Work:

	Points To Be Allowed
Not Susceptible to Continuous Checking of Quantity and Quality	10
In Which Quantity Can Readily Be Checked but not Quality	8
In Which Quality Can Be Readily Checked but not Quantity	6
Where Quantity and Quality can be Checked	3
Where Quantity and Quality Are Systematically Checked	1

FACTOR NO. 11—*Dirtiness of Working Conditions—Multiply by 3.*

Working Conditions:

	Points To Be Allowed
Very Dirty, Hot or Uncomfortable	10
Somewhat Hot or Uncomfortable	7
Disagreeable	5
Average Shop Conditions	3
Nice, Clean Shop	2
Very Clean Work (Offices)	1

FACTOR NO. 12—*Health Hazards—Multiply by 7.*

Health Hazards:

	Points To Be Allowed
Hazardous	10
Dangerous	8
Not Wholesome	6
Wholesome	3
No Danger to Health on Account of Occupation	1

FACTOR NO. 13—*Accident Hazard—Multiply by 3.*

Accident Hazard:

	Points To Be Allowed
Very Dangerous	10
Dangerous	8
Somewhat Dangerous	6
Reasonably Safe	4
Safe	2
Little Chance of Accident	1

FACTOR NO. 14—*Physical Effort—Multiply by 3.*

Handling Equiv. of Lb. per Day	Points To Be Allowed
18,000 to 20,000	10
16,000 to 18,000	9
14,000 to 16,000	8
12,000 to 14,000	7
10,000 to 12,000	6

Table 3 (continued)

FACTOR No. 14—*Physical Effort* (Continued)

Handling Equiv. of Lb. per Day	Points To Be Allowed
8,000 to 10,000	5
6,000 to 8,000	4
4,000 to 6,000	3
2,000 to 4,000	2
Less than 2,000	1

FACTOR No. 15— *Monotony—Multiply by 3.*

Main Cycle	Points To Be Allowed
4 seconds or less	10
4 to 8 seconds	9
8 to 15 seconds	8
15 to 30 seconds	7
80 to 90 seconds	6
1½ to 4 minutes	5
4 to 15 minutes	4
15 to 45 minutes	3
1 to 2 hours	2
2 to 4 hours	1

Table 4

SKILL POINTS AND RATE CLASSIFICATION

Class	Point Rating	Day Rate Per Hr. Dollars
1	150-200	0.50-0.54
2	201-250	0.55-0.58
3	251-300	0.59-0.61
4	301-350	0.62-0.65
5	351-400	0.66-0.69
6	401-450	0.70-0.73
7	451-500	0.74-0.76
8	501-550	0.77-0.80
9	551-600	0.81-0.84
10	601-650	0.85-0.88

points for the different factors, we were able to clear up all questions which arose in the mind of the worker himself by going over the job analysis sheet (Fig. 1) for that particular job with him.

14.   The writer purposely has omitted the tabulation of skill points for each classification which we obtained in our shop by use

of the formula. As mentioned at the beginning, the starting point for making the job evaluation is a complete and detailed description of the work to be done on each job and this is bound to be slightly different for each jobbing shop.

15.   In our opinion the best method of obtaining the correct number of skill points is to actually have some of the workmen themselves discuss the various factors with their foreman and the superintendent, and fix a final figure for each factor which will add up to a fair and impartial total.

16.   Casting prices can only follow labor costs. If they are too high the entire industry suffers as the customers look for substitutes; and if they are too low in enough instances, the entire industry suffers from lack of a fair return for its services.

Mineral Composition and Texture of the Clay Substance of Natural Molding Sands†

By Ralph E. Grim* and Carl S. Schubert,** Urbana, Ill.

Abstract

The authors experimented with samples of eight different molding sands. Six of these sands are in commercial use and two are potential Illinois molding sands. The size-grade distribution of the clay substance is determined, the minerals making up the clay substance of each sand were identified, and the distribution of the important mineral constituents with respect to particle size was determined. Curves of the frequency distribution of the various samples are included.

Introduction

1. The clay substance of a molding sand is defined by the American Foundrymen's Association[1] as that part occurring in particles less than 0.02 mm. in diameter. The physical properties of any sand are closely related to the detailed characteristics of its clay substance[2] and, consequently, properties cannot be well understood until the clay substance has been studied in detail.

2. In the researches herein reported, the size-grade distribution of the clay substance was determined for each one of a number of molding sands selected because the general character of their clay was thought to vary. Also, the minerals which make up the clay substance of each molding sand were identified and the distribution of the important mineral constituents with respect to particle size were determined.

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[1] *"Testing and grading molding sands and clays,"* Am. Foundrymen's Assoc., 1938 edition, pp. 26-27, 157-158.

[2] Throughout this report "clay substance" is used as defined by the American Foundrymen's Association.

† Published with the permission of the Chief, Illinois State Geological Survey.

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Note: This paper was presented before the Sand Research Session of the 43rd Annual A.F.A. Convention, Cincinnati, O., May 17, 1939.

OBJECTIVE

3.   The objective of the present study was to obtain detailed analytical data for the clay substance of various natural molding sands and thereby to develop a basis for a study of the factors controlling some of the physical properties of natural sands.

SANDS INVESTIGATED

4.   The molding sands investigated are listed in Table 1, together with their content of clay substance and their green compression strength at optimum moisture.   Six of the samples are molding sands in commercial use, and two samples are potential Illinois molding sands obtained by the Illinois State Geological Survey in a recent study of the molding sand resources of Illinois.

PROCEDURE

5.   The amount of clay substance was determined by the standard method of the American Foundrymen's Association.[1]

Table 1

CLAY SUBSTANCE AND GREEN COMPRESSION STRENGTH OF MOLDING
SANDS USED IN THIS INVESTIGATION

Sample No.	Clay substance Per cent	Green compression at optimum moisture lb. per sq. in.
1	20.0	18.0
2	10.8	7.5
3	19.2	13.5
4	21.2	13.0
5	16.8	11.0
6	6.6	12.5
7	26.0	14.5
8	46.6	21.0

6.   The size-grade distribution within the clay substance was determined on an aliquot of the original sample by the pipette method, as applied to molding sands.[3]

7.   In order to obtain samples for mineralogical study, another aliquot of the original sample was dispersed in water using NH_4OH as the dispersing agent. The suspension was then allowed to stand until particles larger than 0.02 mm. had settled out.   The

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[3] Jackson, C. E., and Saeger, C. M. Jr., *"Use of pipette in the fineness test of molding sands,"* U. S. Bur. Standards, Jnl. of Research 14, 1935, pp. 59-66.

suspension carrying —0.02 mm. material was then removed and allowed to stand until the +0.01 mm. particles had settled out. The particles settling out of this suspension ranged in size from 0.02 mm. to 0.01 mm. contaminated by some finer material. By repeatedly placing this settled material into suspension and removing the —0.01 mm. particles, a fraction containing only grains ranging from 0.02 mm. to 0.01 mm. was obtained. By a similar procedure, but with different settling times, fractions containing particles from 0.01 to 0.005 mm., 0.005 to 0.002 mm., —0.002 mm., and —0.001 mm. were obtained. NH_4OH was used as the dispersing agent, because on evaporation no salt is left as a residue.

8. The minerals making up the fractions coarser than 0.002 mm. were identified on the basis of their optical characteristics using the petrographic microscope. The components of the fractions finer than 0.002 mm. were identified on the basis of their optical and X-ray characteristics.

9. Determinations of green compression strength and fineness characteristics were made by the standard A. F. A. procedures.

PARTICLE SIZE ANALYSES

10. The results of the determinations of size-grade distribution were plotted in the form of cumulative curves on semi-logarithmic paper. From the cumulative curve of each sample, a frequency distribution curve (Figs. 1A to 8A) was constructed by the graphic differentiation method described by Krumbein.[4] The frequency curves show the relative abundance of various size grades by the area under the curve. For example, the percentage of material between 0.005 and 0.002 mm. in any sample is obtained by dividing that portion of the area under the curve which is bounded by vertical lines constructed at the 0.005 and 0.002 mm. divisions of the horizontal axis by the total area under the curve; e.g., in Fig. 1A, 15 per cent of the total area under the curve lies between the 0.005 and 0.002 mm. verticals, and therefore 15 per cent of the sample occurs in the 0.005 to 0.002 mm. grade size. Thus the relative abundance of any size can easily be visualized or accurately determined.

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[4] Krumbein, W. C., *"Size frequency distribution of sediments,"* Jnl. Sed. Petrology. vol. 4, 1934, pp. 65-77.
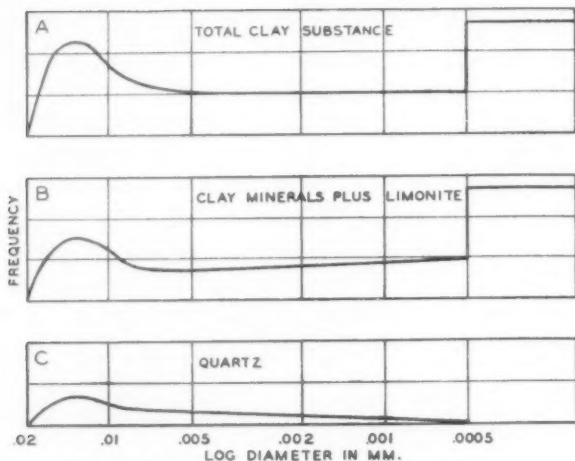
11.   The relative amount of —0.0005 mm. material is represented by the area of the rectogram thus,

$$Per\ cent\ material\ -0.0005\ mm. = \frac{Area\ of\ rectogram}{Area\ beneath\ curve\ including\ area\ of\ rectogram}$$

If the —0.0005 mm. fractions were presented as a continuation of the curve rather than as a rectogram, the curves would extend to infinity since the —0.0005 mm. fraction contains all material from 0.0005 mm. to an infinitely small particle size.

12.   The chief components of the clay substance of the molding sands studied are quartz, clay minerals, and limonite.[5] The distribution and relative abundance of the quartz and clay minerals plus limonite are shown by Figs. 1B, C to 8B, C. The clay minerals and limonite are shown together because together they are chiefly responsible for the strength properties of the sand, and because they cannot well be separated in such material on an accurate quantitative basis.

13.   In Figs. 1B, C to 8B, C the distribution curves of the entire clay substance are broken down into two curves representing, respectively, the distribution of quartz and the clay minerals plus limonite. The distribution curves for the total clay substance are constructed on the basis of weight analyses. The curves for the component mineral are constructed on the basis of numerical values.

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[5] Limonite is used throughout the report for the hydrated ferric iron oxide compounds present in the clay substance.

The shape and specific gravity of the particles are sufficiently alike
so that the curves are comparable.

14. An analysis of Figs. 1A, B, C will illustrate the data
contained in the curves. The area beneath the curve for the clay
minerals plus limonite, added to the area beneath the curve for
quartz is equal to the area beneath the curve for the total clay sub-
stance, and thus in the clay substance.

$$Per\ cent\ quartz = \frac{Area\ beneath\ quartz\ curve}{Area\ beneath\ curve\ for\ total\ clay\ substance}$$

The frequency curves for the quartz and clay minerals plus limonite
represent the size-grade distribution of these constituents in the
same manner that the curve for the entire clay substance represents
the size-grade distribution of the entire clay substance. For example,
in the curve for the clay minerals plus limonite (Fig. 1B), the area
under the curve and between vertical lines drawn at 0.02 and
0.01 mm. is 13 per cent of the total area under this curve, and
therefore 13 per cent of the total clay minerals plus limonite occurs
in the size grade 0.02 to 0.01 mm. The curves are so constructed
that the area under curve B between any grade size, plus the area
under curve C between the same grade size is equal to the area
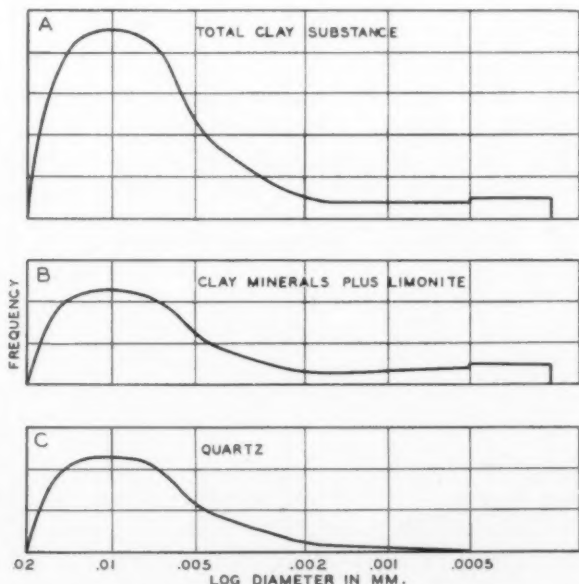
FIG. 2—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 2.

beneath curve A between these grade sizes. Thus, in Fig. 1 the area under curve B between 0.02 and 0.01 mm. is two thirds of the area under curve A between 0.02 and 0.01 mm., and therefore two thirds of the clay substance occurring between 0.02 and 0.01 mm. is clay mineral plus limonite. It is possible, therefore, from the above curves to determine the relative amount of the mineral components in the total clay substance and in any size grade.

ANALYTICAL RESULTS

15.   The clay substance of sample 1 shows a concentration of material in the 0.02 to 0.01 mm. and the —0.0005 mm. grade sizes. Only a small proportion of the clay substance is quartz, and it is concentrated slightly in the coarser fractions. The clay mineral and limonite fraction shows two points of concentration; in the coarsest fraction (0.02 to 0.01 mm.) and the finest fraction (—0.0005 mm.).

16.   In sample 2 there is a pronounced concentration of the total clay substance in the 0.02 to 0.005 mm. grade size. Only about
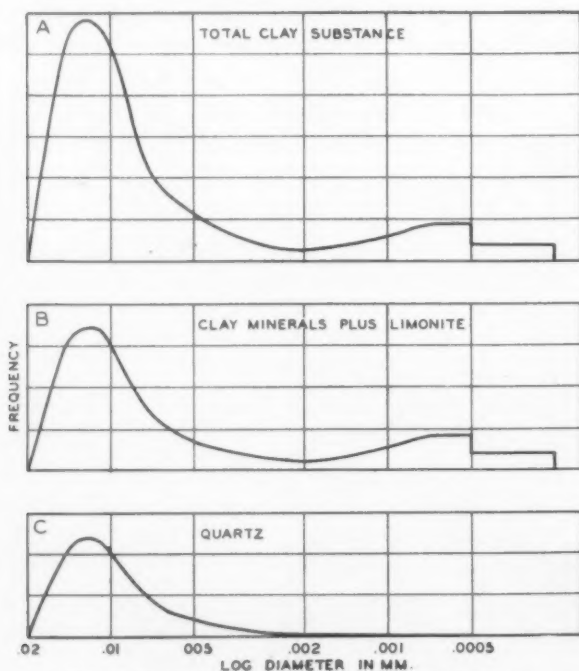
FIG. 3—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 2.
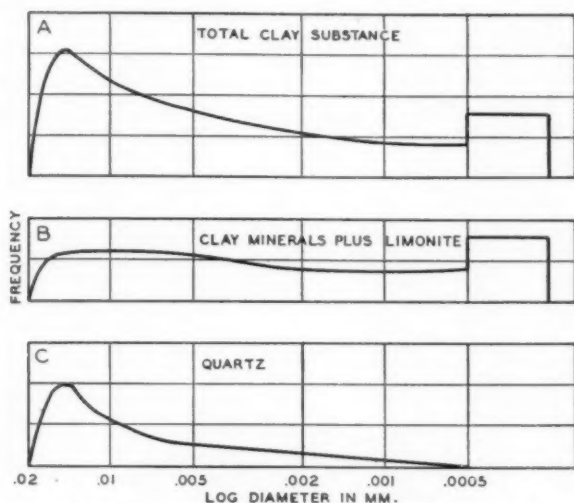
FIG. 4—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 4.

10 per cent of the total clay substance occurs in particles smaller than 0.002 mm. which is frequently considered the upper size limit of true clay. Quartz is almost as abundant as the clay minerals plus limonite, and all constituents show a great concentration in the sizes coarser than 0.005 mm.

17.   The clay substance of sample 3, like sample 2, is chiefly composed of particles coarser than 0.005 mm. Only about 15 per cent of the clay substance is found in particles finer than 0.002 mm. Quartz is considerably less abundant than the clay minerals plus limonite, and all constituents are concentrated in the sizes coarser than 0.005 mm.

18.   The clay substance of sample 4 is composed chiefly of particles coarser than about 0.002 mm. There is a minor concentration in the —0.0005 mm. grade size. Most of the clay substance is composed of clay minerals plus limonite concentrated slightly in the coarsest and finest sizes. A considerable amount of quartz is present, and it is concentrated in the coarsest sizes.

19.   In sample 5, a large part of the clay substance is concentrated in particles larger than 0.005 mm. Clay mineral plus limonite is more abundant than quartz and is evenly distributed except for a slight concentration in the finer sizes. The quartz is concentrated in the coarsest grades.
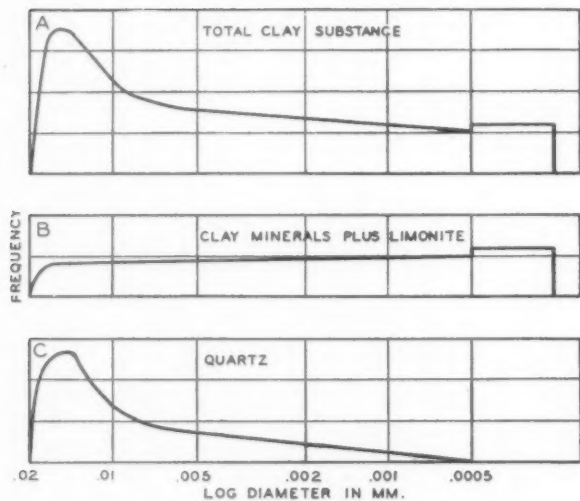
FIG. 5—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 5.
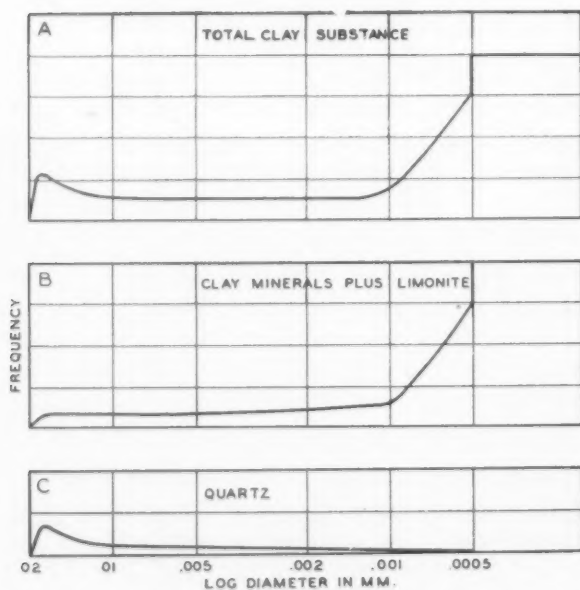
FIG. 6—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 6.

20. A large part of the clay substance of sample 6 is found in particles smaller than 0.001 mm. There is a small concentration in the 0.02 to 0.01 mm. grade size, which reflects the concentration of the minor amount of quartz in this size. The sample is distinctive because of the small amount of limonite plus clay mineral in particles coarser than 0.001 mm., and the great concentration of this material in particles finer than this size.
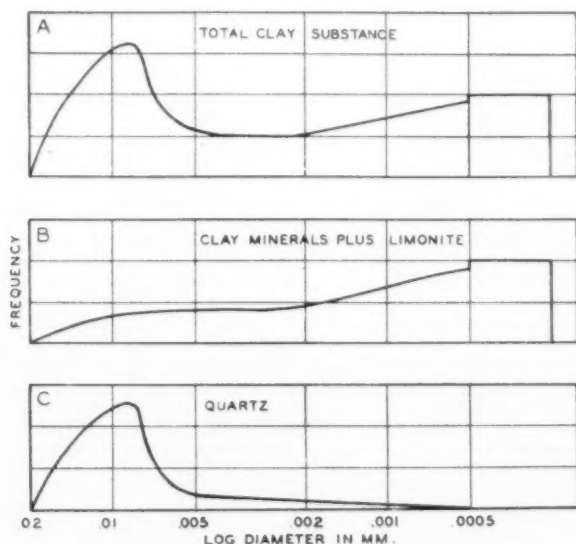
FIG. 7—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 7.

21. The clay substance of sample 7 shows pronounced concentrations in the 0.02 to 0.005 mm. and the finest grades. Quartz is slightly less abundant than clay mineral plus limonite, and it is highly concentrated in particles coarser than 0.005 mm. There is little clay mineral plus limonite in the coarser sizes, this material being concentrated in the sizes finer than about 0.002 mm.

22. The clay substance of sample 8 shows a high concentration in the coarsest size with decreasing amounts in successively finer sizes. About half of the clay substance is quartz in particles concentrated in the coarsest grade sizes. The limonite plus clay mineral is evenly distributed throughout the entire clay substance except for a slight concentration in sizes between about 0.005 to 0.0005 mm.

DISCUSSION OF RESULTS

23.   The analytical data show that in all samples very little quartz occurs in particles smaller than 0.002 mm. and that most of it is present in grains coarser than 0.005 mm. Particles of quartz are angular in shape, and they do not add to the bond strength of a sand. If the clay substance were defined with an upper limit of 0.002 mm., quartz grains would be largely eliminated and the clay substance would be more nearly composed of clay minerals and limonite, which are the materials determining bonding strength.
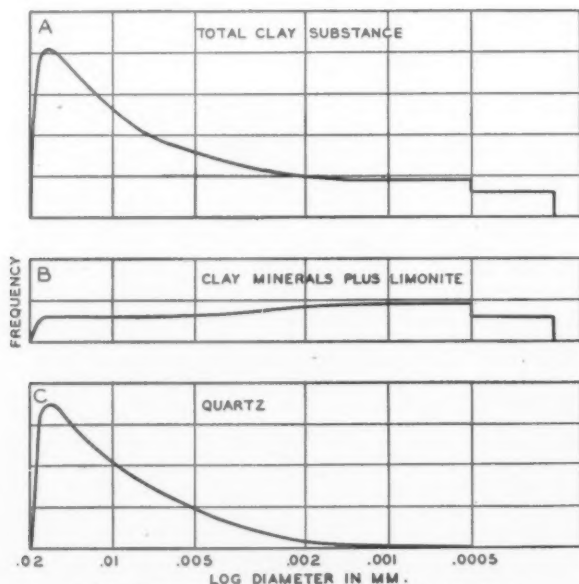
FIG. 8—FREQUENCY DISTRIBUTION CURVES FOR SAMPLE 8.

24.   The clay mineral plus limonite component of the clay substance usually is found in particles smaller than 0.002 mm. However, in some samples much of the clay mineral and limonite is present in particles larger than 0.002 mm. These larger particles are aggregates of smaller clay mineral flakes bound rather loosely together by limonite. In general these materials add little to the strength of a sand when they are present in aggregates. When a sand is mulled or revivified there is a tendency to break up the aggregates thereby releasing the component particles which then add to the strength of the sand. Thus, a sand containing aggregates may maintain its strength or even increase it for the first

several heats. As the sand is used, aggregates are broken up and
bond is developed which may more than compensate for the bond
burned out during the first several heats.

25.   It has long been known that all sands with the same
amount of clay substance do not have the same strength. The ab-
sence of a close correlation between amount of clay substance and
green compression strength is shown by the data in Table 1. Thus
samples 1 and 3 have about the same amount of clay substance
whereas the green compression strength of sample 1 is 18 lb. per
sq. in. as compared with 13.5 lb. per sq. in. for sample 3. Sample 6
has only one third as much clay substance as sample 3, but has a
green compression strength about equal to that of sample 3.

26.   The variations in size-grade distribution and in relative
amounts of quartz and clay minerals plus limonite within the
clay substance explain to a considerable extent the absence of a
close correlation between physical properties and amount of clay
substance. For example, the clay substance of sample 1 contains
only a small amount of a constituent (quartz) which does not add
to its bonding power. Also in sample 1 a large amount of the clay
mineral plus limonite is in the finest size grade (—0.0005 mm.) and
it is well recognized that the finer the size of the particles of a
given type of clay mineral the greater its bonding power. In com-
parison the clay substance of sample 3 contains a large proportion
of quartz and a comparatively small amount of the clay mineral
plus limonite in a fine size. It follows, therefore, that the bonding
power of the clay substance of sample 3 would be less than that of
sample 1. This correlation between the strength of the sand and the
constitution of the clay substance is further substantiated by the
fineness test results in Table 2. The fineness test shows that sand
No. 1 is coarser grained than sand No. 3. Because of the composi-
tion of its clay substance, the coarser sand (Sample 1) has the
higher green compression strength.

27.   Sample 6 shows a very large proportion of its clay sub-
stance in the finest grade size and comparatively little quartz
whereas the clay substance of sample 3 has a large amount of
quartz and a small amount of material in the —0.0005 mm. grade
size. This explains why sample 6 has a green compression strength
about equal to that of sample 3 which has several times as much
total clay substance. Again, the correlation is supported by the
fineness test results in Table 2 which show that sample 3 is a finer
grained sand than sample 6. On the basis of fineness tests alone,

Table 2

CLAY SUBSTANCE AND FINENESS TESTS OF THE MOLDING SANDS

Sieve Size	Per cent							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
40	0.8	0.8	0.4	2.0	0.0	0.4	2.8	0.2
70	3.4	2.8	0.6	22.2	0.8	7.8	20.2	0.4
100	51.0	8.4	21.6	37.0	21.6	55.8	41.0	2.4
140	12.0	4.0	34.6	3.6	9.2	12.6	2.4	1.2
200	6.0	19.4	19.4	2.6	12.0	8.0	1.6	2.6
270	1.6	27.0	1.0	1.2	13.0	3.0	0.8	4.0
—270	5.2	26.8	3.2	10.2	26.6	5.8	5.2	42.2
Clay	20.0	10.8	19.2	21.2	16.8	6.6	26.0	46.6
Total	100.00	100.0	100.0	100.0	100.0	100.0	100.0	99.6
A.F.A. Fineness No.	96	194	125	95	158	95	79	266

sample 3 should have a much higher green compression strength than sample 6. The fact that it does not have much higher strength emphasizes the important effect of the composition of the clay substance on bonding properties.

28.   Sample 2 has a small amount of clay substance, and the clay substance has a large amount of quartz and a small amount of clay mineral and limonite in the finest sizes. The low green compression strength of this sand is, therefore, explained. The importance of the composition of the clay substance is again emphasized by the fineness tests of sample 2 (Table 2). Sand No. 2 is a fine-grained molding sand and on this basis alone a greater green compression strength would be expected. The size of the clay particles and the large amount of quartz in the clay substance, however, cause the strength to be low. A further check of Tables 1 and 2 and Figs. 1 to 8 shows that all the molding sands investigated exhibit the same general correlation between their green compression strength and composition of clay substance as the ones selected and quoted herein.

29.   Variations in the relative abundance of quartz and clay minerals plus limonite and in the size-grade distribution within the clay substance are not the only factors tending to prevent a close correlation between amount of clay substance and physical properties. Another factor is the variation in the type of clay mineral present. In a previous paper,[6] it has been shown that the bonding power of a clay will vary depending on whether illite, kaolinite, or

⁶ Grim, R. E., "Elements of the petrographic study of molding sands and bond clays." Preprint 39-23. To be presented at annual convention in Cincinnati, May 15-18, 1939.

montmorillonite is the constituent of the clay. The identity of the
clay minerals, their relative abundance, and the relative abundance
of the limonite are given in Table 3. It is evident from this table
that the clay mineral in all the samples is essentially a mixture of
kaolinite and illite. Samples 6 and 7 also appear to contain mont-
morillonite. The relative amounts of these clay minerals and the
character of the illite would have to be determined in considerable
detail before a close correlation with physical properties could
be made.

SUMMARY

30.   It has been shown that there is considerable variation in
the size-grade distribution within the clay substance of molding
sands, in the relative amounts of quartz, clay minerals, and limon-
ite which compose the clay substance of different sands, and in the
size-grade distribution of these mineral constituents in the clay
substance of various sands. These variations explain to a consider-
able degree the absence of a close correlation between amount of
clay substance and physical properties of natural molding sands.

31.   The quartz grains are concentrated in the coarser frac-
tions of the clay substance, and only a very small amount of
quartz is found in particles smaller than 0.002 mm. The clay miner-
als and limonite occur in all sizes within the clay grade, and are
frequently concentrated in the coarsest (0.02 to 0.01 mm.) and
finest (—0.0005 mm.) fractions. These materials in the coarsest
fraction are present as aggregates which are broken down on using
so that strength is developed in the sand during the first few times
the sand is used.

Table 3

COMPOSITION OF THE CLAY MINERAL PLUS LIMONITE PORTION
OF THE CLAY SUBSTANCE

Sample	Composition
1.	Kaolinite VA; illite A; limonite A.
2.	Kaolinite A; illite A; limonite A.
3.	Kaolinite VA; illite (?); limonite A.
4.	Kaolinite VA; illite A; limonite VA.
5.	Kaolinite A; illite A; limonite VA.
6.	Illite VA; kaolinite (?); montmorillonite (?); limonite C
7.	Kaolinite A; illite A; montmorillonite (?); limonite A.
8.	Illite VA; kaolinite A; limonite C.

VA = 40 per cent +;   A = 40-20 per cent;   C = 20 per cent —.

32. The clay minerals in the sands investigated are kaolinite and illite. Two of the sands also appear to contain small amounts of montmorillonite.

ACKNOWLEDGMENTS

33. The X-ray analyses were made by W. F. Bradley of the Illinois State Geological Survey. R. A. Rowland, also of the Illinois Geological Survey, assisted in making the determinations of size-grade distribution and green compression strength. It is desired also to acknowledge the counsel of W. F. Krumbein of the University of Chicago in preparing the graphs portraying some of the analytical data.

DISCUSSION

Presiding: H. S. WASHBURN, Plainville Casting Co., Plainville, Conn.

H. L. DAASCH[1] *(Written discussion):* The contentions of the authors might be stated: (1) quartz particles should not be considered effective in bond strengths and (2) equally coarse aggregates of true clay minerals are ineffective in bond strength. These lead to (3) sub-micron clay minerals plus limonite are "chiefly responsible for strength properties of the sand." A number of comparisons will be made on these premises.

Samples 1 and 3 are noted in paragraph 25 of the paper. Table 3 shows quite similar clay mineral composition. If less than one micron size clay mineral content is considered for each, we find a ratio of approximately 4:1; a ratio much different than the strength ratio of 18:13.5.

Samples 6 and 3 are also compared in paragraphs 25 and 27. Note however, that if clay which is smaller than one micron is considered, a ratio of such clay contents is practically 2:1. Yet strength ratio is 12.5:13.5.

Again, compare samples 2 and 5. The below one micron size clay content is approximately in the ratio of 1:5 while the strength ratio is 7.5:11.0. Table 3 shows very similar clay composition.

The writer does not feel that conclusions should be too quickly drawn on the data now available on clay. For example, kaolinite should, according to Grim[2], occur in particle sizes larger than 1 micron. Grim indicates further that illite is most likely to occur in similarly 1 micron and larger particles. Let us now consider samples 1, 2, 3

and 5 which have been compared in previous paragraphs. If kaolonite is eliminated and illite similarly but reasonably not considered because of the likelihood of greater than 1 micron size; we have left primarily limonite in sub-micron size. In three of the four cases the percentage of this limonite is 20-40 per cent. According to the premises of the authors, we would conclude that such limonite would have to account for strength property characteristics.

Again, let us consider statements of Casberg and Schubert[3] and Grim[2] which indicate that base exchange capacity is a criteria of strength properties. Consider further the statements of Grim[2] that kaolinite has relatively low ionic exchange and that illite may often by similarly low. This would bring us to the peculiar conclusion that base exchange variations for the samples 1, 2, 3 and 5 would be accounted for by (1) low exchange capacity material or (2) by limonite.

The writer does not, of course, concur in these conclusions. They are based on generalized statements propounded by the authors in the present paper and in the references quoted.

The point the writer would make is that a "general correlation between green compression strength and composition of clay substance" is not necessarily shown by the data submitted. When viewed in the light of preceding paragraphs we do not "explain to a considerable degree the absence of a close correlation between amount of clay substance and physical properties."

The writer has produced a wide variety of molding sand strength properties by adjustment or change in the sand component without any change in type or amount of bond material. Variations in molding sand strength properties need not involve ipso facto any differences in the clay.

Finally, the writer would like to ask the authors if any control is offered in the use of the pipette size analysis and the A.F.A. strength tests which would permit a correlation study as made in the paper. This query is prompted by a recent report by Grim[4]. After discussing the effect of water in fineness and use tests, Doctor Grim writes: "In such correlation work, the objective should be to determine the effective particle size i.e., the particle size of the clay as it is usually used." So far as the writer can determine, the authors have neglected this previous admonition in the present correlation study.

A. SAMUEL BERLIN[5] *(Written discussion)*: This paper, like others by the same authors, is extremely interesting. It constitutes a valuable contribution on the influence of clay particle size on green strength of molding sands. Since the increase in the green strength depends, to a

[2] R. E. Grim, *"Petrographic Study of Molding Sands,"* Transactions American Foundrymen's Association, Vol. 47, 1939.

[3] Casberg, C. H., and Schubert, C. E., *"An Investigation of the Durability of Molding Sands,"* Bulletin 281, Illinois Engineering Experiment Station, April, 1936.

[4] Grim, R. E., *"Relation of the Composition to the Properties of Clays,"* Jour. Am. Cer. Soc. May, 1939.

[5] American Manganese Steel Division, New Castle, Del.

certain extent, upon the breaking down of the large size particles into
smaller ones as for example, the mineral kaolinite, I think it would be
advantageous to find a rapid method to determine the chemical and
mineral content of the clays so that we would be able to control the
green strength of the molding sands in those cases where these factors
are important.

Having an economical and positive method of controling the particle
size of the clay so that it would approach the (−0.0005 mm) fraction,
I think would be the solution of quite a few of our molding difficulties
that are attributed to green strength failure.

R. E. GRIM and C. E. SCHUBERT (*Reply to written discussions*):
Mr. Daasch has arrived at conclusions from our data that are obviously
in error because he has failed to understand our statements or has
read into them meanings which they do not contain.

We state that "particles of quartz . . . do not add to the bond
strength of a sand." The point is made that the bonding power of the
clay substance rests in the clay mineral and limonite component and
not in the quartz component. We realize, and in fact point out, that
the total bond strength of a natural bonded sand is partly dependent
on the size of quartz grains which the clay mineral and limonite must
bond. This, in no way, argues against the idea that the seat of the
bonding power is in the clay mineral and limonite and not in the quartz.

Daasch has somehow read into our statements the idea that only
the portion of the clay mineral and limonite occurring in particles less
than 0.001 mm. in diameter has bond strength. He then proceeds to
show that the ratio of the −0.001 mm. clay mineral and limonite
fractions of various sands is not the same as the ratio of the bond
strength of the same sands. We state clearly (in paragraph 23 for
example) that bond strength rests in the clay mineral and limonite
component. Nothing is said anywhere that only −0.001 mm. clay
mineral and limonite has bond strength. What is stated is that the
bonding power of this component of the clay substance tends to increase
as the particle size decreases. The ratio between the −0.001 mm. clay
mineral and limonite for different sands should, of course, not be the
same as the ratio of the bond strength of the same sands because this
−0.001 mm. material does not alone determine strength of the sands
even when the clay minerals are the same. As pointed out all the clay
mineral plus limonite component has strength, the fineness of the
quartz must be considered, and the character of the exchangeable base
also exerts an influence. What we believe our data show convincingly
is that the relative total amount of clay mineral and limonite in the
clay substance of a molding sand is important in determining its
strength, and also that the initial strength of two molding sands,
equivalent in every way except in the size distribution of the clay
mineral and limonite particles and aggregates will be different—the one
containing these components in the finer size having the higher strength.

Grim states that kaolinite occurs in particles rarely smaller than −0.001 mm. and that most illite occurs in particles about this same size. Grim also states that some illite occurs in finer particles. Daasch concludes, as the clay minerals in the samples are chiefly kaolinite and illite, that there are no clay minerals in the −0.001 mm. size grades and that it is all limonite. As Daasch has thought that only —0.001 mm. material has bonding power, he concludes that the bonding power is only possessed by the limonite. This is, of course, an erroneous conclusion.

Some of the kaolinite and illite occur in the −0.001 mm. fractions and the entire clay mineral plus limonite fraction is responsible for bonding power. Grim is perhaps responsible for Daasch's false conclusion here, by not stating that kaolinite rarely occurs in particles smaller than *about* 0.001 mm. The point that Grim wished to emphasize was that kaolinite and most illite tend to occur in particles larger than *about* 0.001 mm., and that they are not easily broken down by agitation in water into particles much smaller than this size. This is a generality encountered by all students of clay mineralogy.

Kaolinite is shown to have a low base-exchange capacity, and illite is known to have low or moderate base-exchange capacity. These are the clay mineral components of the samples studied. We have not determined the base-exchange characteristics of our samples, and consequently do not know whether such determinations would substantiate or deny the findings of Casberg and Schubert. Because the clay minerals are those having low capacity seems to us to be no reason to conclude, as Daasch has done, before any determinations are made that such determinations would not agree with Casberg and Schubert.

In reply to Daasch's question about particle size analysis, we would say that we followed the Bureau of Standards procedure to which reference is made. We point out that the pipette analyses show some clay mineral and limonite in all size grades and that it is frequently concentrated in the coarse (because of aggregates) and in the finest size grades. These fractionations were made to show first the particle size distributions of quartz in the clay substance. It should be emphasized that Grim's statements of "effective particle size" referred to clay minerals only and not to quartz. The fractionations were made also to determine the particle size of the clay minerals and limonite when prepared by a method suggested for molding sands. The authors made no attempts to correlate the size grade determinations *in detail* with the bonding properties. This cannot be done in detail because of the "effective particle size" concept, and, as pointed out before, because other factors control bond strength. The justifications for the statement of Daasch that some general conclusions cannot be recognized because details cannot be worked out is not clear to us. In our minds the discussion of the break down of the aggregates with the liberation of bonding power as the sand is used is an illustration of the importance of "effective particle size" rather than a neglect of it.

Finally we feel that the data presented by us show that the abundance and size grade distribution of the quartz and clay mineral plus

limonite "explain *to a considerable degree* the absence of a close corre-
lation between amount of clay substance and physical properties of
natural molding." We inserted the expression "to a considerable
degree" because these "are not the only factors tending to prevent a
close correlation" (paragraph 29).

In reply to Mr. Berlin we wish to say that at the present time
the method for determining the mineral composition of the clay sub-
stance of molding sands and for studying the size grade distribution
of the clay mineral particles is long and somewhat involved. The
method embodies a combination of size-grade fractionation and petro-
graphic analysis. The petrographic analysis identifies the minerals by
X-ray and optical analytical data. Mr. Berlin is quite correct, it
would be very advantageous to find a shorter method for this work, and
we hope that this may be possible.

MEMBER: Is it possible to separate the limonite from the clay
minerals?

DR. GRIM: There are ways of getting rid of the iron oxide. You
can remove it, but it is frequently impossible to remove it quantitatively
and still retain the clay minerals with their original character.

H. RIES[6]: In paragraph 6, the authors state that the size-grade
distribution of the grains was determined with a pipette. Have the
authors in their laboratories ever used the hydrometer method?

DR. GRIM: Yes, we have used the hydrometer method. The chief
reason for the pipette method here was to obtain fractions for micro-
scopic study. In the case of the pipette, you draw off a certain amount
that represents the material finer than a given size grade and then
you have something to study for the identification of the constituents.
We have no objection to the hydrometer method. We chose to use the
pipette method simply because it gave us samples for mineralogical
analyses.

MEMBER: Would the amount of limonite present be indicative of
the effective life of the clay?

MR. SCHUBERT: According to the hydration and dehydration curve,
I might answer it in this way. Limonite breaks up at a very low tem-
perature and gives up its water of crystallization, or what might be
called water of crystallization. Therefore, a lot of limonite in any
natural sand or any bonding substance should cut down the life of the
sand. Now, we have not yet determined the durability or life of sands
of the natural variety. We reported[7] at the 1937 convention on what
we call synthetic sands. Those were of the montmorillonite and
kaolinite type and we did not include plain limonite and silica sand.
From the hydration curves alone, we know that limonite, being a hy-

⁶ Cornell University, Ithaca, N. Y.

⁷ Schubert, C. E., "*A Correlation of the Physical and Chemical Properties of Clays
With the Durability of Molding Sands*," Trans. American Foundrymen's Association,
Vol. 45, (1937), pp. 661-688.

drated ferric oxide, does give off its water at very low tempera-
tures and in ordinary casting work, you would expect that sand, if it
had an appreciable amount of it in there, to burn out very readily,
and therefore your life would be cut down to some extent.

MEMBER: In these two comparative cases, 1 and 3, could the
author give us an indication as to the difference in the amount of
limonite?

MR. SCHUBERT: That is contained in Table 3.   The limonite was
about 20 per cent in both samples.

Quality Pattern Equipment for Diesel Engine, Tractor and Road Machinery Castings

By J. E. Kolb*, Peoria, Ill.

Abstract

The fundamental principles and methods of pattern making, as practiced at the Caterpillar Tractor Co., in relation to foundry, machine shop and engineering requirements, are discussed herein. The writer discusses pattern making tools, equipment, materials, and Caterpillar Tractor Co. pattern shop procedure. In conclusion, he states that in order to obtain quality castings you must have quality pattern equipment.

Introduction

1. It is rather difficult to talk about pattern making without saying something about foundry practice; and likewise, one could hardly discuss foundry practice without thinking about pattern equipment. The two branches of the industry are so closely linked together — that one cannot exist without the other.

2. One might consider it a rather broad statement if we should say that: "If it were not for the skill, knowledge and dexterity of the pattern maker, all mechanical industry would be seriously hampered." For without it, we would not have our modern, luxurious automobiles of today; the fast-moving, streamlined, diesel driven, air-conditioned passenger trains; the airplanes, and most of all, the modern agricultural implements, without which the farmers of today would be seriously handicapped. Imagine ourselves going back to primitive covered wagon days — to plowing with a stick drawn by a couple of oxen.

3.   Thus the foundry industry, of which the pattern shop is an important part, has kept pace with the ideas of the engineers in producing those things which make life more comfortable and worthwhile. It is said the agricultural implement business gave the foundry industry its first real production problems. Greatest advance in foundry practice has been made since the introduction of the motor car, airplane and tractor. The foundry industry has met all demands placed upon it — and is ever ready for new ideas.

4.   Many key men managing mechanical and automotive industries have had pattern making as the foundation of their training. Pattern making calls for the highest type of workman, and involves a great deal of mental dexterity, with a corresponding rate of pay. Unfortunately, however, our universities and trade schools are not in a position to give this important branch of the industry the education necessary to enable a student, upon completion of a pattern making course, to qualify for a position as a pattern maker. Due to such inadequate training now existent in our universities, organizations must institute an apprentice training program within their own pattern shop, in order to obtain skilled pattern makers.

5.   The Caterpillar Tractor Co. has a very well balanced program of training apprentices, through the pattern making apprentice program, which includes actual work in the shop with related classroom instruction. It is from this system that we expect to obtain our future trained pattern makers.

6.   A person might wonder just what problems confront the pattern maker. It is true he receives detailed drawings of just what the engineering department would like to have in the way of a finished casting ready for assembly in the machine to be built. But we must also realize that a blue print is somewhat limited in carrying dimensions, and that many of the details and irregular shapes cannot be developed fully for portrayal on paper. Therefore, the pattern maker becomes a component part by developing shapes and blending contours which cannot be shown through the medium of a blue print. The engineer is not much concerned just how this piece or part is to be made in the foundry.

7.   In this period of high production of intricate castings, the pattern maker has an opportunity to prove his value to the foundry industry. The more simple and practical a job can be made, the better it is for everyone concerned.

DEFINITION OF "PATTERN"

8.   The word "pattern" in itself represents but little of the necessary equipment to make a casting. We must think of "pattern equipment," consisting of: patterns, core boxes, flasks, core rubbing and grinding gauges, overall gauges for locating the cores in the mold accurately, core dryers and core plates. Without any of these individual items, a pattern itself would be useless for production purposes!

PATTERN SHOP TOOLS AND EQUIPMENT

9.   The modern pattern shop of today is a complete manufacturing unit in itself, using wood working machines such as: band saws, circle saws, swing cut-off saws, jointers, planers, routers, wood lathes, disc and spindle grinders, and uniform work benches.

10.   In the metal shop will be found: engine lathes, drill presses, shapers, vertical milling machines, Van Norman milling machines, Cincinnati Universal milling machines, metal band saws, Keller duplicating machines, flexible shaft machines, and a variety of different size face plates and angle blocks.

11.   A pattern shop is not complete without an aluminum foundry with sufficient molders, skilled in pattern manufacturing practices, to produce very accurate pattern castings, such as: match plates, dryers, core boxes, and other pattern castings required by the shop. This lends itself to better control of accuracy and pattern

FIG. 1—KIT OF TOOLS USED BY WOOD PATTERN MAKERS AND GIVEN TO GRADUATE APPRENTICES.

manufacturing economy. When castings in excess of 300 lb. are required, they are usually purchased from outside independent commercial shops, due to their larger molding and melting facilities.

12. In Fig. 1 is shown a kit of tools which is used by the wood pattern makers, and which is given to a graduate apprentice upon completion of his course. This set represents a value of $147.

13. In Fig. 2 is shown a kit of tools which the metal pattern makers use, and which is presented to a graduate apprentice upon completion of his course, representing a value of $119.

14. While these two illustrations do not show as many tools as some journeymen may have, it does give a good general idea of the tools required by those who work at these two branches of the pattern making trade. The more expensive tools, such as micrometers, etc., are furnished by the company and issued by the tool check system.

PATTERN MAKING MATERIALS

15. The most needed materials for making pattern equipment are: Northern Cork Pine, Mahogany, Brass, Aluminum, Gray Iron, Steel, Plaster of Paris, Leather, Wax, Shellac, and Glue.

16. In order to present a little clearer picture of the importance and volume of patterns made within the pattern shop of the Caterpillar Tractor Co., the following figures are offered:

January 1, 1938 to January 1, 1939

Northern Cork Pine...................55,413 Bd. Ft.
Mahogany ....26,060 Bd. Ft.
Reclaimed Aluminum ....56,797 Lb.
Pig Aluminum 99 Per Cent Pure........ 7,085 Lb.

TOTALS
63,882 Lb. Aluminum
174,761 Lb. Gray Iron

17. These figures represent the major items and quantity of materials which were worked into pattern equipment in the Caterpillar Tractor Co. pattern shop. This is not the entire amount of pattern equipment required, as a number of patterns for steel, malleable iron, brass and aluminum are purchased on the outside.

18. A large staff of skilled workmen, including apprentices were employed 40 hr. per week for the entire year. However, many pattern makers are not devoted at all times to making new patterns.
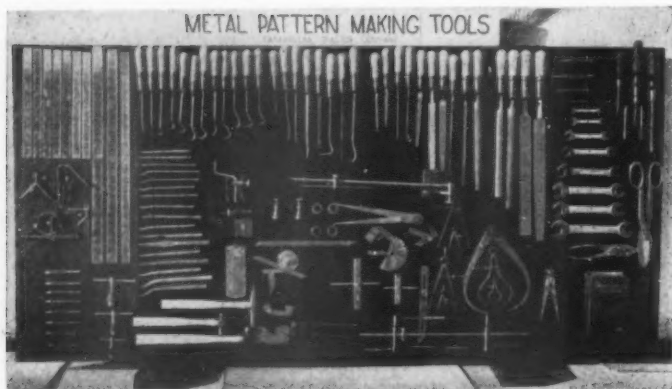
FIG. 2—KIT OF TOOLS USED BY METAL PATTERN MAKERS AND GIVEN TO GRADUATE APPRENTICES.

Since our pattern shop is directly connected with our production foundry, considerable time is utilized in making engineering changes and repairs to old pattern equipment.

STEADY SUPPLY OF WORK

19. The general flow of work usually is received from the channels of the engineering, tool design and planning departments — many times in the form of orders for wood models required by the engineering department for observation purposes; experimental patterns from which very few castings are to be made; and the usual orders for production patterns, which are thoroughly analyzed to determine what type of pattern shall be made.

20. Every pattern shop must have a steady flow of work to maintain operating economies. Therefore, a corporation pattern shop should be equipped to take care of normal requirements only. Thereby, steady year 'round employment is provided for a definite number of men. Our company has followed this practice for 8 yr., and we feel that it has contributed greatly to the cause of all concerned, to the extent that a large number of men have enjoyed steady work; the company has profited in obtaining finer craftsmanship due to the coordinated effort that can be developed and maintained due to the perpetual contact with the job.

21. Many thousands of dollars have been spent by the Caterpillar Tractor Co. in pattern purchases. This work originates from the overflow due to peak period requirements. A commercial jobbing shop serves a very important purpose in our industrial

world, by making themselves available to take care of the overflow
of work, often occurring in corporation shops; as well as taking
care of many manufacturers' pattern requirements that do not
desire to provide facilities for doing their own work.

PATTERN SHOP PROCEDURE

22.   The general procedure which is carried out in the pattern
shop is of a very definite and well thought-out plan. It is contrary
to the old practice of simply laying a blue print before a pattern
maker and asking him to make a pattern. Instead the blue prints
go through the hands of several pattern engineers. These men con-
tact various heads of the production engineering department for
further information, possibly to present suggestions for beneficial
changes — all with the thought in mind of obtaining the essential
features required in the finished product, as well as foundry and
machine shop production economies. This pattern engineering
department functions as a part and for the use of the pattern shop,
and it also designs the pattern equipment for the making of
patterns and castings which are purchased from outside sources.

23.   The blue prints received from the engineering department
are very carefully scrutenized. Then detailed drawings are made
showing where core prints are needed, and also the partings and
location of the pattern in the flask. In fact, every fundamental
detail necessary for the pattern maker's use is figured out before
the job is turned over to him for construction. In addition to this,
the number of man hours required to build complete pattern equip-
ment, the number of board feet of wood, other required materials,
(whether it be aluminum, cast iron or brass), the number of core
dryers, etc. are estimated. All this information is compiled and
presented to the superintendent of the pattern shop for his check.
It is then turned over to the production manager of the foundry,
who also passes on it, and finally it reaches the office of the foundry
manager, who is primarily interested in the estimated number of
hours. Thus, he follows up on the completion of the job and checks
the efficiency of the department. This procedure is the same as that
required in a jobbing pattern shop, because the estimate in the
jobbing business, in a measure, is the basis of the selling price.
If it has taken more hours than the estimate, it may represent a
profit or loss in the finished pattern product. Also a complete
follow-up system is used showing: the dates the pattern orders are
received; the dates the patterns are to be started; the hours re-
quired to build each pattern, and a promised completion date.

24. A control on work is maintained by this method and progress can be observed from time to time. It also shows man hours required against man hours available, which more or less decides whether equipment will be purchased to meet delivery requirements of patterns and castings.

PROBLEMS CONFRONTING A PATTERN MAKER

25. In order to answer some of the problems which confront a pattern designer he must ask himself these questions: What is the size of the casting? How many can be placed in a mold? What molding unit in our plant does it fit best? If the castings are to be made by an outside vendor, what equipment do they have available for the making of this part? What flasks have we on hand that can be used? This latter question is very important because in our type of production very often we are called upon to make as high as 53 different types of castings in one flask. One should realize that if there are many patterns on hand and if each had its own flask for storage purposes, that in itself would be a very complex problem, let alone the problem of bringing flasks in and out continuously. Where is the best place to part the pattern? How is it best to part core boxes to facilitate sand removal from pockets within the interior of the casting? What position should a casting set in the mold to obtain the best pouring and cooling conditions? —and many other problems too numerous to mention.

WOOD PATTERN MAKING

26. The problems of a pattern maker working with wood are many, for he is working with a material that nature has spent many years in producing. He must be more resourceful than the metal pattern maker, because all he has to work with are the drawings of the piece part and other fundamental information as previously mentioned, a lumber pile, his own personal tools, and the machines in the shop. On the other hand, the metal pattern maker picks up the job where the wood pattern maker leaves off. He receives a casting made from the master pattern constructed by the wood pattern maker, who has originated and incorporated in the master pattern, many of the more difficult problems that have to be considered in producing the finished pattern. He is, in a sense, a high class machinist who understands the fundamentals of molding; knows the requirements of a pattern; machines or files it to size, and then assembles the metal patterns according to the layouts and blue prints furnished him.

27.   From the time a tree has been felled, until it reaches the pattern maker's bench, it has gone through a process of seasoning which should take at the very least 2 yr. The wood pattern maker must use care in selecting the wood to be used, and even greater care in piecing it together.

28.   If the wood is not properly glued and screwed together, a pattern maker cannot expect to return to his bench the next morning, and find his work in its true shape. Even then, the moisture in the air sometimes causes the wood to expand, contract and warp.

29.   We have only to look at the trunk of a tree which has been sawed, and count the rings representing the years of growth, to give us a very good idea as to the age of the wood with which we are working. These rings in the section of the tree also represent in a large measure the grain. It is these rings in the boards which have been sawed from the sides of the logs, which cause a lot of the pattern maker's troubles.

30.   In Fig. 3, *A* shows a sketch representing the cross section of a log. *B* represents a board from the center of the log, or a piece of quarter sawed lumber, which is the best piece that can be obtained from any log, unless the entire log should be quarter sawed, which is an expensive operation. You will note that the grain in this piece is running true in every detail, and will resist the warping hazards much better than the board in *C,* which was cut without regard to the growth rings of the log. This type of board would probably warp in the direction opposite the center of the growth rings, even though it is properly seasoned or kiln dried.

31.   The best way to counteract this warpage is to cut this board into narrow strips, as shown by the horizontal lines in *C;* turn the strips so that the growth rings are in as near a relation to the face of the board, as shown in *B*, and glue the strips together as shown in *F*.

32.   If the board should be cut close to the center of the tree, the year rings would form a rather short arc. In this case, the growth rings in each strip should be reversed so the action of one strip would counteract the action of the strip next to it, should it have a tendency to warp.

33.   The method of cutting a board in segments is shown in *D,* and *E* illustrates the method of glueing them together in preparing a piece of lumber for turning a round disc shaped pattern such as
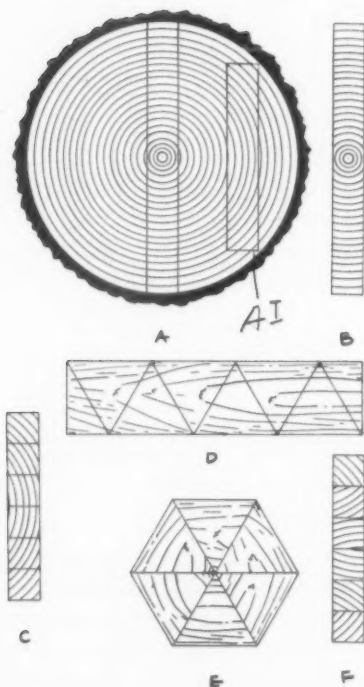
FIG. 3—DRAWING OF A TREE USED IN WOOD PATTERNMAKING. (A) CROSS SECTION OF A LOG.
(B) BOARD FROM THE CENTER OF THE LOG. (C) BOARD CUT FROM AI SECTION WITHOUT REGARD
TO GROWTH RINGS OF TREE. (D) BOARD CUT TO COUNTERACT WARPAGE. (E) METHOD OF
GLUING STRIPS TOGETHER. (F) BOARD FROM AI POSITION CUT AND GLUED READY FOR PATTERN
USE.

a clutch plate or flywheel. By overlapping the glued joints of each layer of segments a very strong pattern, and one that is free from warpage, will be the result.

34. After the wood pattern is carved to shape, it must be protected from the moisture in the molding sand, and given a protected surface, to facilitate the drawing of the pattern from the mold, and protect the wood from the abrasive action of the sand. For this purpose we use the best grade of orange shellac dissolved in wood alcohol.

35. There is a difference of opinion as to what moisture content in wood is acceptable, after kiln drying. We believe that 5 to 7 per cent moisture would be acceptable at point of consumption, after receiving and storing for at least 6 mo. within your own pattern shop. In this way the wood may become acclimated to room

temperature and moisture, and a great deal of unsatisfactory experience in wood distortion would be overcome.

36.   The cost of the wood involved in the making of patterns constitutes the very smallest part of the total cost. It is the man hours that run into money.

SHRINKAGE

37.   Just a word about shrinkage, which is also synonymous to the word contraction. Nevertheless, there is a difference in the actual meaning of the word, from a pattern maker and foundryman's standpoint. It is true we have scales such as the $\frac{1}{8}$ in. shrink for gray iron; $\frac{1}{4}$ in. for steel and 5/32 in. for aluminum, but what actually does take place in a casting after it has been poured? Contraction takes place as well as shrinkage. In casting a large fly wheel with very heavy sections, feeder heads are placed at proper junctions to take care of this actual shrinkage of metal during its process of solidification; and at the same time there is a contraction in the dimensions of the casting. Generally, a casting stops contracting when it has reached room temperature. In bygone years it was not unusual in the making of a pattern for an engine block to use three different shrink or contraction scales; such as one for the height of the casting; another for the width and another for the length. This, however, has been straightened out by our becoming better versed on the subject, and by making cores and molds to compensate for these conditions.

PATTERN EQUIPMENT

Aluminum

38.   The use of aluminum for the making of patterns reaches tremendous proportions. Many reasons, such as: to produce lightness of core boxes that are to be handled by hand; ease of working it from a machine speed, as well as hand tools, have been formulated for using aluminum in the metal departments. This can readily be understood when the general ratio of weight is of 3 to 1 in favor of aluminum as compared to cast iron.

Magnesium

39.   Magnesium has, in recent years, become quite popular and this has a weight ratio of 11 to 7 in favor of magnesium as compared to aluminum. The problems of handling magnesium are considerable, however, and unless it is a matter of weight, there is no great object in using magnesium.

Cast Iron and Brass

40. Cast iron and brass are also used for making patterns and core boxes, and these materials have their place in the making of patterns.

41. A great deal also has been done in chrome plating cast iron, as well as brass, and it does have some especially good points. A little harder surface is obtained, and many more castings are produced from a pattern which has been treated in this manner.

42. The introduction of various types of machinery for the making of castings has naturally presented different problems. It is surprising how many castings can be obtained from a pattern made of wood molded by the sandslinger method. We believe it is safe to say that wooden patterns rammed by a sandslinger will last much longer than a wood pattern rammed by the old fashioned manner of hand ramming.

Shellac

43. Shellac is something which in the last few years has received a great deal of attention, when we realize that denatured alcohol is made more or less by a synthetic method, and poorer results are experienced during hot weather by the use of synthetic alcohol. The genuine wood alcohol on the other hand seems to reduce these problems to a minimum.

Match Plates

44. The average layman does not realize the amount of work involved in producing a pattern for an ordinary match plate, and at times is astonished at the cost of a transmission case for a tractor, or a pattern for an engine block for an automobile. When he is informed that a pattern for some of these parts costs as much as a complete five or six room home, which is equipped with modern conveniences throughout — it is only then that the amount of work involved is brought forcibly to his attention.

45. Let us show you an example of the above by glancing at Fig. 4, which is the complete equipment for the making of a small air cleaner pipe, as shown in Fig. 4 *B*. Fig. 4 *G* shows the master pattern in the follow board with a frame around the master pattern, from which the pattern plate *D* was cast. Fig. 4 *N* is the master pattern for one-half of the metal core box, *H*. Fig. 4 *I* is the knitting frame, laying on the other half of the metal core box. Fig. 4 *F* is one-half of the master pattern for the core box that has
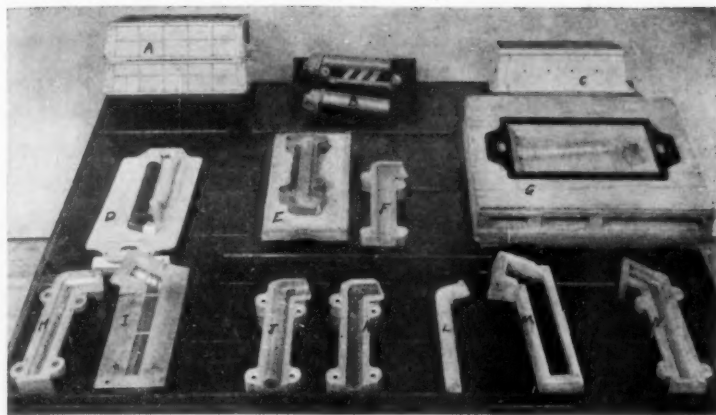
FIG. 4—VARIOUS PIECES OF PATTERN EQUIPMENT USED IN MAKING A SMALL AIR CLEANER PIPE. (A) SLIP FLASK. (B) AIR CLEANER PIPE CASTING. (C) SLIP JACKET. (D) PATTERN PLATE. (E) FOLLOW BOARD AND METAL PATTERN FOR MAKING ALUMINUM CORE DRYERS. (F) ONE HALF OF MASTER PATTERN FOR CORE DRYER. (G) MASTER PATTERN IN FOLLOW BOARD USED IN PRODUCING PATTERN PLATE. (H) ONE-HALF OF METAL CORE BOX. (I) KNITTING FRAME ON CORE BOX. (J)-(K) FINISHED ALUMINUM CORE DRYER. (L) CORE FOR CASTING. (M) BEDDING FRAME. (N) MASTER PATTERN FOR ONE-HALF OF CORE BOX.

been reworked into a master pattern for the dryer. Fig. 4 E is the follow board and metal pattern for making the aluminum core dryers. Fig. 4 K is a finished aluminum core dryer. Fig. 4 M is the bedding frame which was used to bed the core made in the master core box, for lightening out the inside of the metal pattern cast in the plate. Fig. 4 A is the slip flask and Fig. 4 C is the slip jacket used to produce casting, B.
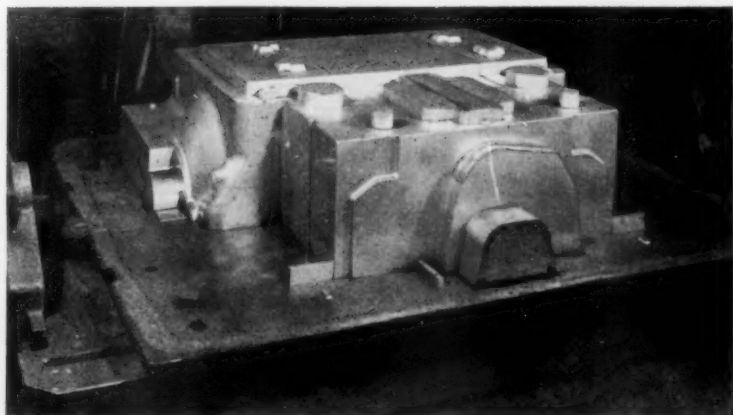
FIG. 5—DRAG HALF OF A LARGE TRANSMISSION AS CASTING WEIGHING 3,275 LB.

46.   You can readily see there is a great deal of labor involved in the making of this equipment — but not necessarily much material. Man hours represent by far the major cost of a pattern.

47.   Our match plates are usually 7/16 in. thick, with a $\frac{3}{8}$ in. upset. The adoption of this upset, which is quite a common practice, is to prevent a great deal of shifting of the mold, after the flask has been withdrawn, and it also aids materially in fitting the joints and preventing run-outs.
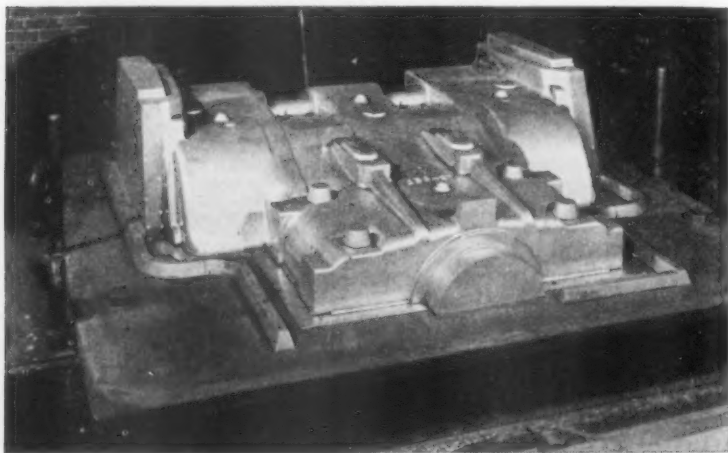
FIG. 6—COPE HALF OF TRANSMISSION AS CASTING OF FIG. 5.

Follow Boards

48.   Follow boards are invariably made for all match plate work, where patterns are cast integral with the plate. This is to eliminate the making of joints by the match plate molder, as well as to obtain a more accurate job. It also eliminates much back draft due to improper setting up of the pattern during the process of molding.

49.   Aluminum tapered slip flasks with double guide pins at each end, and with machine guide plates are used in connection with all match plates.

TYPICAL PATTERNS

50.   Fig. 5 represents the drag half of a large transmission case for Caterpillar Tractor Co., producing a casting weighing 3,275 lb. This is made entirely of aluminum, in four sections, to facilitate going through the metal pattern shop.

51.   Fig. 6 is the cope half of the same transmission case. This pattern is also made in four sections. These sections are securely bolted together before mounting on cast steel plates, and are molded on a large air jolt electrically rolled over and pattern draw type machine.

52.   Fig. 7 is a view looking into the interior of the casting, showing the various bearings and the clean cut design, eliminating pockets that might be dirt-catchers, and which would cause contamination in the oil.

53.   Fig. 8 is the same casting placed within a checking fixture, where all finish lines are scribed. Thus, when it is received in the machine shop, it can be immediately placed in fixture without any juggling for the accurate and economical machine operations.
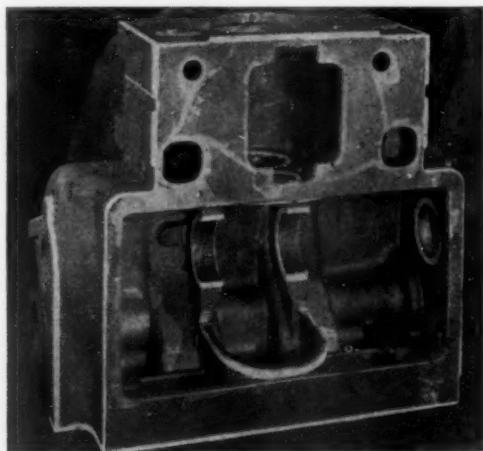
FIG. 7—VIEW OF INTERIOR OF TRANSMISSION CASTING SHOWING VARIOUS BEARINGS AND CLEAN CUT DESIGN.

54.   A very interesting method of making a pattern for producing a two cylinder horizontal starting engine for diesel work is represented in Fig. 9. The lower view at A and B represents the original pattern of the conventional type, with all its core prints, and resembles the shape of a block. However, when one visualizes the amount of intricate core work, and the placing of this work in the mold, one can readily see that even at best, it is a blind job.

55.   This pattern was redesigned at the saving of a number of pounds of core sand, wherein the entire core assembly was placed on a slab. Side cores put into position and placed on a slab,
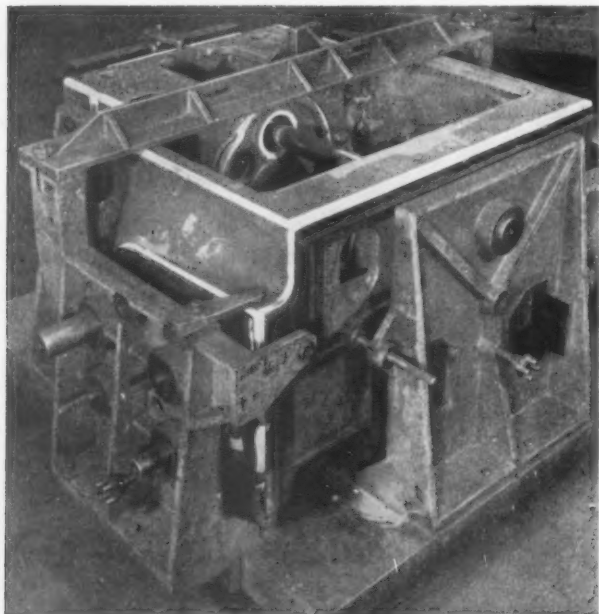
FIG. 8—TRANSMISSION CASTING OF FIG. 7 PLACED WITHIN A CHECKING FIXTURE. NOTE LOCATING POINTS AND GUIDE BARS.
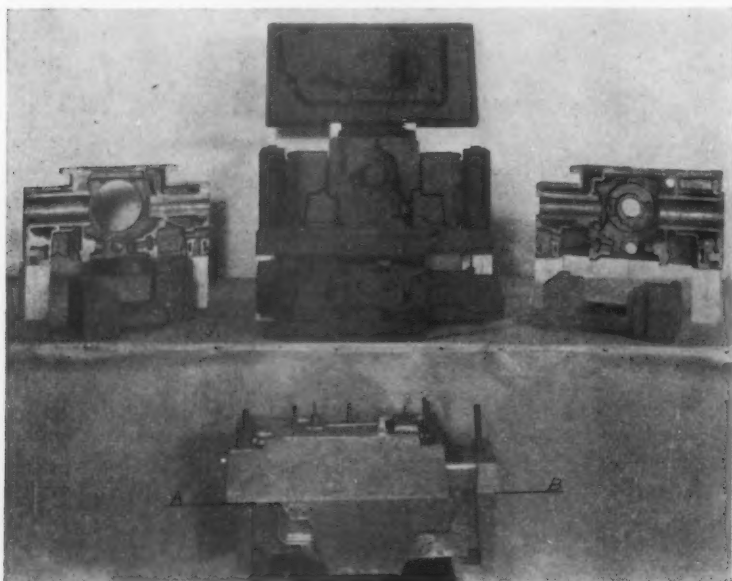
FIG. 9—TWO CYLINDER HORIZONTAL STARTING ENGINE. A-B VIEW SHOWS PATTERN AS USED ORIGINALLY. UPPER VIEW SHOWS ASSEMBLY AND CASTING AFTER PATTERN WAS REDESIGNED.

give the assembler a very simple method of assembling the job, and
at the same time he can see every detail. Side cores then are as-
sembled and a cover core is placed in position. This mold is
clamped in a very simple manner, and these molds are now ready
for pouring. Considerable increased efficiency in producing this
casting has been achieved through the redesigning of this pattern,
together with considerable saving in cost.

56.   In discussing pattern making, one cannot help but branch
out into other phases and methods of making castings. Permanent
molds have become very popular in the last few years, notwith-
standing the fact that they are as old as the industry itself. But
the modern type of castings with their very complicated parts, has
brought the permanent mold phase of the industry into a very
prominent position.

57.   We can refer to car wheels as being somewhat of a semi-
permanent mold, inasmuch as they have large iron sections which
form the tread of the wheel commonly referred to as the chill. So
it is with parts used in the automotive and tractor industries —
from the forming of anything such as carburetor bodies, chill track
rollers — and many other parts too numberable to mention.

58.   One method of making a track carrier roller is shown in
Fig. 10. The complete casting, *G,* has been removed from the sand
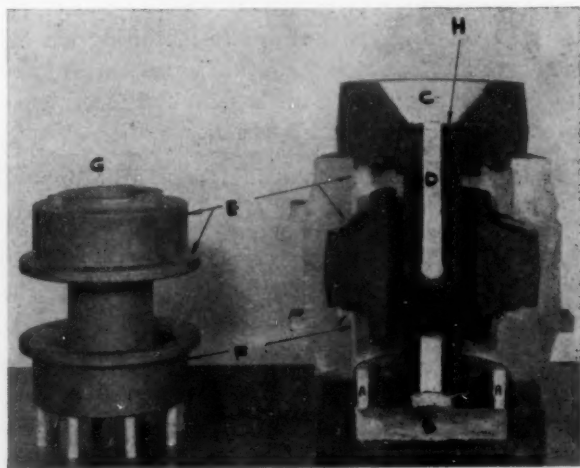
Fig. 10—Showing Casting and Mold set-up of a track carrier roller. (A) Pencil
Gates (B) Bottom Pouring Basin. (C) Top Pouring Basin. (D) Sprue. (E)-(F) Tread
Face exposed to chill. (G) Finished Casting.
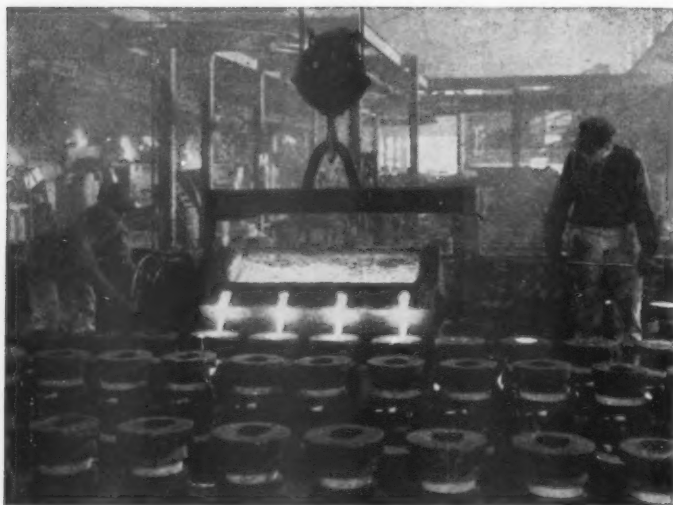
FIG. 11—TRACK CARRIER ROLLERS POURED FOUR AT ONE TIME.

and processed through the cleaning room, together with the eight pencil gates supporting it.

59. These pencil gates are located in Fig. 10 in the picture to the right, which represents the entire cross section of an assembled mold, which is marked at A.

60. A very important feature in pouring a casting of this type is the basin B. A great deal of experimenting has been done regarding the volume of iron contained in this basin, to eliminate blemishes on the casting at F. This basin is fed from the top basin at C, the iron running down the sprue D.

61. It is very desirable to obtain a chill of approximately 3/16 in. on the tread at E and F.

62. It requires six different cores for casting this particular part. The center core at H is a very interesting one for the reason that the down sprue runs through the center of this core. All these cores are made by the core blowing process.

63. As a chill wash, a great many different preparations have been used, with more or less success. However, after a great deal of elimination, a material that is mixed with five parts of good plumbago and dissolved into ten parts of a desirable solvent, has proven to be the most successful.

64.   Up to the present time, annealed malleable iron has proven more durable than cast iron for chills, because it withstands the alternating extreme heating and cooling of the chill at the sharp corners.

65.   Fig. 11 shows how four track carrier rollers are poured at one time.

66.   The accuracy of patterns and core boxes are only a few of the many things that our modern methods of producing castings have brought about. A great deal of machinery in a foundry does much simpler work than it does in a machine shop. We have reference to core grinding, where it is essential to grind cores down to the accuracy of thousandths of an inch — especially when a number of these cores are to be pasted together. The rotary table grinding machinery, shown in Fig. 12, for the grinding of cores is an interesting development, as are also thickness and slip gauges for checking cores. Fig. 12 represents a rotary machine, grinding crank case cores to an accurate measurement, as there are twelve of these cores required in order to make a six cylinder diesel engine.

FIG. 12—ROTARY TABLE MACHINE GRINDING CRANK CASE CORES TO AN ACCURATE MEASUREMENT.

CONCLUSION

67. We believe everyone who is connected in any way with foundry and pattern shops will agree that the progress made has been more or less forced upon us by the production method of machining castings. Sometimes in machine shop practice it is not unusual to spend many thousands of dollars for machining simple castings, but the quantity justifies the expense.

68. So it is with pattern work — we must analyze our job thoroughly; know as much as possible how castings are going to be handled, and make equipment that is accurate. When castings of a large quantity are desired, by no means allow the cost to be a question as to how patterns should be made.

69. There is no doubt but what there is a lot of truth in the saying: "In order to obtain quality castings, we must have quality pattern equipment."

DISCUSSION

Presiding: VAUGHAN REID, City Pattern Works, Detroit, Mich.

WM. M. BALL, JR.[1]: With regard to the use of chaplets, what if your casting metal is an alloy which would not permit of the use of chaplets? We find chaplets very poor in brass and bronze as we are always troubled with leaks around them.

MR. KOLB: When making high pressure castings, what could be used in the place of chaplets? The core must have some support, of course, but if additional core support is needed what can be used to hold that core in position without using chaplets?

CHAIRMAN REID: Oftentimes brass and copper chaplets are used that will fuse into the casting. Some foundrymen even go so far as to use regular steel chaplets in brass—using any metal chaplet to which the metal poured will knit.

MR. BALL: Such chaplets do not work well for us. We have tried all kinds of chaplets and even heated them. What we do, when confronted with the need for additional core support in pressure castings, is to make a double pattern. Then we have three points of supports. To compensate for the big flask used, we get two castings. Our trouble is that the purchaser who sends in patterns has them made outside our plant. He gives us a pattern for a single casting and we can not afford to change it.

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[1] Edna Brass Mfg. Co., Cincinnati, O.

MEMBER: I do not quite see why you used that brass strip in ramming the cores in the box.

MR. KOLB: If you take the two halves of the box and ram them full of sand and strike off flush with the face of the box, and then book the box together without any excess sand between those two halves, after the core has dried, it will drop apart. The sand is not knitted together.

MEMBER: One thing, that is valuable about the use of the brass strip, is that it does keep your core round.

MR. KOLB: With the different diameters we encounter, we allow a different thickness of this knitting frame and we allow a difference in the overlap from the edge of the box. This knitting frame overlaps the edge of the box approximately a sixteenth of an inch ($\frac{1}{16}$-in.), which is the same thickness as the knitting frame itself. When the box is pressed together we have a completely round core.

MEMBER: You make the box that much less than a half circle?

MR. KOLB: No, it is a full circle without a plate. The sand is compressed that much more when the two halves are put together.

J. G. GOLDIE[2]: I think one of the main reasons for getting the round core by using this knitting frame, or bedding strip, is because of today's production demands. Perhaps there may be 10, 15, or 20 core makers on the same core on one job. Using the bedding strip method you are sure that every core has the same thickness of sand.

J. D. BURLIE[3]: We use this strip also for another purpose. We have a number of gray iron castings, with a ½-in., irregular, pin core. Here, it is necessary to make the core in a split box. We found that, without the strip, the core frequently does not fill out to the edges perfectly. Then the iron runs into the core along the parting, leaving a fin on the inside of the casting where it is hard and expensive to chip out. If this bedding or knitting frame is used, you can get a full round core. In some cases, we have gone very slightly over full, and we would rather have a slight depression in the casting than to have the fin. That is another application of the bedding strip method.

MEMBER: Mr. Kolb, you say you have various thicknesses of the frame, depending upon the size of the box. How do you arrive at that thickness?

MR. KOLB: We have no set rule to follow but use our judgment. I would say if this particular box was twice the diameter it is, we would only increase that plate about $\frac{3}{32}$-in. That judgment only comes from experience. Even that might not quite satisfy the core maker for we do run into the human element, where the core maker packs one-half or both halves differently from the man next to him. If the man

[2] Foundry Instructor, Cleveland Trade School, Cleveland, O.
[3] Western Electric Co., Chicago, Ill.

using the box packs the sand at the exact consistency for the amount of fill-in for the knitting frame, you are all right. But if they give it to the man next to him, who packs his sand in lighter, then that plate should be thicker.

MEMBER: When you buy your casting, does the vendor engineer make the pattern according to his own specifications?

MR. KOLB: We co-operate with them. We advise anyone who has any of our castings to make, that our services are available to them. We like to help them and we like them to help us. We do everything we can in the way of assistance in designing a pattern or getting changes from the engineering department, for simplification of molding problems.

MEMBER: In this core, why did you not have your vent through the middle instead of bedding it in?

MR. KOLB: The vent was placed below the center of the box so that it would not interfere with the use of the knitting frame. The two halves of the box can be filled with the vent rod in place and then booked together. The vent rod can now be drawn from the box. This eliminates the possibility of closing the vents when the box is booked together with the extra sand that is provided by the use of the knitting frame.

MEMBER: Has shellac given you any trouble due to gumming?

MR. KOLB: For a while, we used denatured alcohol with shellac. It was hard to get wood alcohol, with which we found that we obtained better results, particularly in the summer. Shellac with wood alcohol is clearer and dries harder than with denatured alcohol which leaves it muddy. We are not using any lacquers or enamels now, as we have tried them and see no particular advantage in their use.

MEMBER: I might add that I have used lacquer to some extent and found it always flakes off.

MR. FRANK CECH[4]: We have made many experiments with shellac and we find the main trouble with denatured alcohol is the denaturing material. Formaldehyde has a bad effect on shellac. We used methyl alcohol, which is ordinarily called wood alcohol. We never have any trouble.

MR. KOLB: There is only one place in the country that we have found that produces genuine wood alcohol. That is in Tennessee.

MEMBER: How do these aluminum match plates made in plaster molds compare with the other types used?

MR. KOLB: I do not like to commit myself for maybe they are all right. We had one sample plate sent to us. Our experience with it was not so good, due to the fact our plate, cast in sand, was just as

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[4] Cleveland Trade School, Cleveland, O.

close to dimension as the one we received that was pressure cast. Another point is the time element. By the time you make a little single wood pattern, or if you give the concern the order to make the master pattern themselves, the time required in correspondence and shipment of the pattern after it is completed is too great. We can make the pattern ourselves and cast it in sand, and have it done before we are through with the correspondence with regard to price and all the detailed information they would like to have.

MEMBER: I use these match plates all the time. I have bought hundreds of them.

MEMBER: We happen to make those pressure plates. I was talking to the general superintendent of a large foundry and he said they would not use anything else.

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